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GEOLOGICAL EXPLORATIONS EAST OF THE ANDES IN ECUADOR[1]

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ABSTRACT

An area of 8,000 square miles, lying east of the Andes in Ecuador, was explored in 1921. The old Indian towns of Archidona, Tena, and Napo are in the northern part; Macas, the largest settlement in the Oriental region, is at the southern extremity of the area. Astronomical observations were made as a check on the plane-table traverse, which was carried over all routes of travel. Collections of fossils, mostly from the vicinity of Napo, establish one horizon of Turonian (Eagle Ford–Benton) age, and a second of middle Albian (mid-Comanchean) age. Unfossiliferous red beds occur above this Cretaceous section, and below it are sandstones and volcanic rocks. The Napo Cretaceous beds are petroliferous. Cretaceous rocks east of the Andes have been described from Colombia, Venezuela, Peru, Bolivia, and the Argentine Republic, but this is the first description of such rocks from eastern Ecuador.

INTRODUCTION

BASIS OF THE PAPER

This paper presents an account of observations made by the authors while engaged in geological work in eastern Ecuador for the Leonard Exploration Company, through whose courtesy it is published. Five months during the latter part of the year 1921 were spent in the field.

HISTORY OF EXPLORATIONS

So energetic was the Spanish conquest of Peru that seven years after the execution of Atahualpa, the last Inca king, the Spanish sent an expedition into what is now eastern Ecuador. Gonzalo Pizarro, brother of

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Francisco Pizarro, the famous conqueror of Peru, marched northeast from Quito in February, 1541, descending the valley of the Rio Coca. Although many died from famine and disease, a few men under Orellana drifted down the Napo and Amazon to the Atlantic.

Many since that time have crossed this area: travelers, explorers, and priests. The striking thing about all these journeys is the small amount of geographic knowledge and the entire lack of geologic knowledge recorded.

Alexander von Humboldt,[1] who journeyed in the Andean Highland in 1801–2, climbed the volcanic peaks around Quito but did not descend the eastern slopes of the Andes. He is the first, however, to record Cretaceous rocks in the Andean highlands.

In 1867 James Orton of Rochester, New York, made a trip across the Andes from the Pacific side and descended the Rio Napo to the Amazon and thence to the Atlantic. He published an account of his trip in book form,[2] and also a record of his physical observations[3] which were of great scientific value. He carried two mercurial barometers, a Wollaston boiling-point apparatus, and thermometers.

The best map of Ecuador was prepared by Theodor Wolf, a German, who taught for thirty years at the University of Quito. In 1892 his map was published in Leipzig at the expense of the Ecuadorian government. A small-scale edition in atlas form was prepared by Felicísimo López in 1907.

The authors have previously published a map[4] of the area explored by them. It is the first map of this area based on a plane-table survey. It shows for the first time the exact location of the volcanic peak of Sumaco and the details of the Rio Napo from the town of Napo to the mouth of the Rio Coca.

ACKNOWLEDGMENTS

Dr. José Louis Tamayo, president of Ecuador in 1921, received the writers in Quito and gave them letters to government officials and others which were of great assistance in traveling through the Oriental region.

[1] Alexander von Humboldt, "Geognostische und Physikalische Beobachtungen über die Vulkane des Hochlandes von Quito," *König Preuss-Akademie der Wissenschaften Berlin*, Verhandlungen, February 9, 1837.

[2] James Orton, *The Andes and the Amazon* (New York: Harper Brothers, 1870), 356 pages.

[3] James Orton, "Physical Observations on the Andes and the Amazon," *American Journal of Science*, Vol. 46 (New Haven, 1868), pp. 203–13.

[4] Joseph H. Sinclair and Theron Wasson, "Explorations in Eastern Ecuador," *Geographical Review*, Vol. 13 (April, 1923).

Mr. Nicolas G. Martinez, of Ambato, arranged for the special train from Ambato to the end of the railroad line at Pelileo. He also furnished copies of maps of the Curaray Railway Survey which were used in starting the surveys east of the Andes. Mr. Manuel I. Rivadeneyra, of Napo, furnished Indian carriers and acted as interpreter among the Indian tribes. The success of the expedition was partly due to his good management. Governor Burbano de Lara, of the Oriental region, gave official welcome to the party at Tena. The Dominican Fathers at Canelos will always be remembered for their hospitality and assistance, as will also the government officials and town council at Macas under the command of Manuel J. Bejarano. The end of the journey at Riobamba was made pleasant by the friendly welcome of Colonel Enrique Rivadeneyra. Special mention should be made of the assistance of representatives of the Leonard Company in Ecuador.

THE AREA EXPLORED

The area explored (Fig. 1) lies east of the Andes between 0° 30′ and 2° 30′ south of the equator and between meridians 77° 00′ and 78° 10′ west of Greenwich. This area extends approximately 100 miles eastward from the foot of the Andes and 170 miles north and south. The old Indian towns of Archidona, Tena, and Napo are in the northern portion of the area. The town of Macas is at the southern extremity.

ROUTE OF TRAVEL

Entrance to the region was from the Pacific seaport of Guayaquil by rail over the American-built railroad to Ambato, which is on the main railway line between Guayaquil and Quito. Ambato is on the central plateau of the Andes, 196 miles by railroad from Guayaquil, and is 8,435 feet in elevation. At Ambato another railway line was followed to its terminus at Pelileo, 21 miles east. Here Quechua Indians from the Oriental region transferred all baggage to back packs, and the journey down the Rio Pastaza was resumed on foot. At Mera on the Rio Pastaza, 56 miles east of Ambato, the survey was started. It followed an obscure Indian trail northeastward to the valley of the Rio Anzú, which was descended to Napo, a small settlement on the Rio Napo, 48 miles from Mera. Here headquarters were established for the exploration of the northern portion of the area. From the town of Napo a stadia survey was made down the Rio Napo to the mouth of the Rio Coca, a distance of 98 miles.

Returning to Napo, the expedition traversed the Papallacta trail, which is the old route from Quito to Napo, with side trips on the rivers which were crossed. This trail was followed a distance of 29 miles from

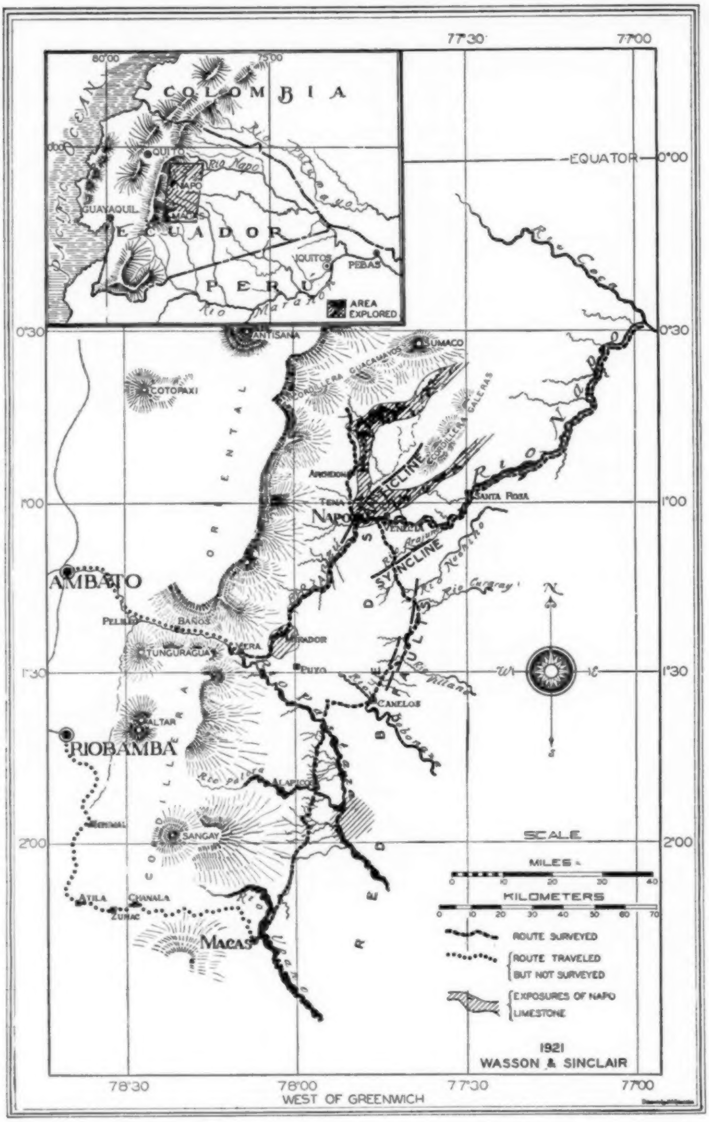

FIG. 1.—Inset shows location of area explored along the eastern base of the Andes in Ecuador. Large map is the area explored made from plane-table survey. The route surveyed and principal geological features are shown.

Napo to the foot of the Cordillera Guacamayos, a low spur running east from the Andes. After another return to Napo, a trail was cut and surveyed southward through the forest to Canelos on the Rio Bobonaza, 56 miles from Napo. Then the traverse continued southward from Canelos on old Indian trails across the Rio Pastaza to Alpicos on the Rio Palora, and farther south to Macas on the Rio Upano, 126 miles by traverse measurement from Napo. At Macas the surveys terminated and the return to civilization was made up the Rio Upano to its headwaters at the summit of the Andes (map, Fig. 1) and down an affluent of the Pastaza to the railroad at Riobamba, a city on the Andean plateau, 35 miles south of Ambato, the starting-point. The approximate distance covered on foot and by canoe, counting some back-tracking in the vicinity of Napo, was 600 miles.

METHODS OF SURVEY

In the absence of any accurate map of the Oriental region, the boundaries of the concessions examined had been defined in terms of latitude and longitude. In order to locate these the expedition carried, besides the Gurley alidade and plane-table outfit, two accurate watches and an engineer's transit with vertical arc, with which observations for azimuth, latitude, and longitude were made.

The two watches were compared with the ship's chronometer on the voyage from Panama to Guayaquil, and one was set to Greenwich mean time and accurately rated for daily variation. These watches were carefully packed and transported across the mountains. At Mera the first observation was made on the sun at noon for longitude, but clouds prevented any check by star observations. Repeated observations on the sun established the longitude at Napo as 77° 49′ west of Greenwich. Observations for longitude at other places were not taken because of the increasing errors in the time carried by the watches, but this was unnecessary, as all other points were tied to Napo by the plane-table traverse.

Latitude was determined at Napo, the mean of many star observations being 1° 03′ south. At other points along the survey where weather conditions permitted, observations were made for latitude as a check on the plane-table traverse.

Starting at Mera where the Rio Pastaza emerges from the Andes, a plane-table traverse was run over all the route as far as Macas. A 300-foot cotton tape coated with paraffin was used on the forest trails. A new tape was made every week. Direction was obtained by sighting on the position of the man ahead as determined by the sound of his voice. Cor-

rections for lack of alignment of the tape were made on the ground. On open rivers like the Napo a more accurate survey was made by the stadia method with the plane table and telescopic alidade.

The survey of the route of travel was mapped on a scale of 1:48,000. A smaller map on a scale of 1:480,000 was also constructed in the field in order to triangulate the mountain peaks. A simplified form of this map is the one published in Figure 1.

Elevations were established with aneroid barometers. The curves of daily variation which were made at several points along the route of travel showed very uniform atmospheric conditions from day to day. High barometer at nine in the morning is followed by a slowly falling barometer until four in the afternoon, when the maximum low is reached. This maximum low is generally followed by a gentle rain which falls for two or three hours. Barometric curves at several points in the area are so nearly alike that the same correction table can be used for all stations.

PHYSIOGRAPHIC DIVISIONS OF THE ROUTE

PACIFIC COASTAL PLAIN

In order to reach the Amazon plain in which explorations were carried on, the Pacific coastal plain and the Andes Mountains were crossed. The coastal plain is about 50 miles wide, is low-lying, and is covered with tropical vegetation, with the exception of plantations of sugar cane and cacao here and there. The streams are short and torrential, emerging suddenly from the Andes where they drop débris in the form of alluvial fans and cones. Over the lowlands they are sluggish and muddy, following meandering courses.

Guayaquil is the only large seaport in Ecuador. It is situated on the Rio Guayas near its junction with the Gulf of Guayaquil, which is virtually an estuary of the Rio Guayas. From Guayaquil the railroad crosses the coastal plain and then abruptly rises to the summit of the Andes at an elevation of 10,000 feet. A vertical distance of about 9,000 feet is negotiated by rail in 20 miles of direct line, although the course of the railroad is several times that distance. The vegetation changes suddenly at about 6,000 feet from tropical to semi-arid.

ANDES MOUNTAINS

The Andes Mountains consist of a plateau about 9,000 feet in elevation, from which rise many volcanic peaks. These have been described as forming an eastern and western cordillera, but topographic studies show no such regularity. These peaks, however, divide the plateau into basins, in one of which lies the town of Ambato. The plateau region is

treeless and semi-arid, and the volcanic peaks are covered with perpetual snow. On the lower slopes of the mountains there are considerable areas under cultivation, and some of the bottom lands are irrigated. The climate is temperate and much fog exists at certain seasons.

The Ambato basin is drained by rivers flowing into the Amazon. The Rio Patate flowing from the north, and the Rio Chambo from the south, unite near Baños to form the Rio Pastaza. Both these tributaries are of moderate size, and at the junction where they join to form the Pastaza they are deeply intrenched in volcanic ash.

The most prominent characteristic of the Andean uplift in Ecuador is its narrow base and precipitous sides, the mass being less than 90 miles wide at the base and 40 miles wide at the top. The plateau summit is about 9,000 feet in elevation and from this general level rise volcanic cones to elevations of 18,000 and 20,000 feet. Among the more prominent peaks are Chimborazo, Cotopaxi, Tunguragua, and Sangay, the cones of Cotopaxi and Sangay being particularly symmetrical. The sides of the volcanic peaks are covered with extrusive volcanic débris, much of the material on the plateau at their base being in the form of pumice. The general aspect of the slopes of these volcanic peaks gives the impression of very recent volcanic activity.

THE PASTAZA VALLEY

The Rio Pastaza formed by the junction of the Chambo and the Patate, 25 miles east of Ambato, flows due east, cutting deep into the eastern slope of the Andes, and is a natural route of travel from the highlands to the Amazon plain. The valley is deeply intrenched in volcanic débris east of Ambato, and on the northern slopes of Tunguragua is cut through recent lava flows. From the junction of the Chambo and Patate, at an elevation of 6,300 feet, the river descends to 3,800 feet at Mera, 31 miles farther east, where it emerges from the wall of the Andes. Five miles east of Baños is Agoyan Falls, 200 feet high, where the river plunges over a lava bed. Below these for several miles small waterfalls enter the gorge through hanging valleys.

The Pastaza as it emerges from the mountains changes into a braided stream of swift current, in time of flood transporting much material. Great boulders are carried or rolled along the bottom and their grinding can be heard some distance from the stream. After leaving the Andes the Pastaza flows southeastward across the south-central part of the area under discussion to join the Amazon, 250 miles west of Iquitos, Peru. Looking from a point on the east slope of the Andes out on the lowland

extending eastward from the base of the mountains, one gets the impression, aided by the thick forest cover, of a uniformly sloping smooth plain. An examination of this, however, shows it to be a region which for 100 miles from the base of the Andes slopes from 4,000 to 1,000 feet above the sea and is made up of more or less dissected interstream areas and river valleys, some of which are 1,000 feet below the interstream summits.

GEOGRAPHY OF THE REGION EXPLORED

DRAINAGE

The region explored on this eastward-tilted plain may be divided into a northern and a southern area, such division being made on the basis of the two main lines of drainage. The northern area is drained by the Rio Napo and its tributaries. The Rio Anzu, the principal tributary of the Napo, flows from the vicinity of Mera, 40 miles northeast, to the village of Napo, where it joins the Rio Napo. All previous maps showed this river as flowing due east from the foot of the Andes. The Rio Napo has its source in the belt of heavy rainfall, and is a torrential stream subject to sudden floods. At Napo the river is 300 feet wide, with banks of limestone. Below Napo the stream becomes progressively wider, with many side channels, the banks being lower and made of alluvium. In this lower section the stream is excessively braided due to the lessened gradient and to the material carried in flood time, which, as the current slackens, is deposited in the channels, forcing the water to find new courses. At the junction with the Coca the Napo is 2,000 feet wide and here flows in a single channel, is more sluggish and meandering, carrying mud and silt rather than sand and gravel.

The area explored north of the village of Napo is drained by the southward-flowing Misahualli and its tributaries, the Jandachi and the Hollin. These streams are all similar to the upper course of the Napo and all drain into it. The northern boundary of this area is formed by a mountain ridge, the Cordillera Guacamayos, extending eastward from the Andes as a spur. A few miles east of the termination of the Cordillera Guacamayos stands Cerro Sumaco, an isolated volcanic peak with an elevation of about 12,700 feet, which seems to rise out of the Amazon lowland. This peak was located and its elevation determined for the first time by this expedition. Also in this area north of the Napo is the Cordillera Galeras, whose peaks were located by triangulation from the Rio Napo survey. They rise to an elevation of approximately 6,000 feet. They were not explored.

The two principal southern tributaries of the Napo, the Arajuno and

the Curaray, were crossed during the survey from Napo to Canelos. These streams rise near the headwaters of the Anzu in the highlands east of Mera. Their courses were not surveyed, but where crossed they are small, clear streams in well-defined channels. The stream divides rise to nearly 1,000 feet.

The southern area is drained by the Rio Pastaza, which, as previously noted, flows southeastward after emerging from the Andes at Mera. Its northern tributaries, the Villano, Bobonaza, and Pindo, all rise in the high land east of Mera. At the mouth of the Rio Pindo the Pastaza is a rapid stream about 600 feet wide at low water. South of the Rio Pastaza the first tributary is the Rio Palora, which at Alapicos is a rapid stream flowing between banks 100 feet high. Between Alapicos and Macas the trail surveyed passes close to the base of the Andes and through a region of torrential rains. Many small, rapid streams flowing eastward were crossed. They carry no sediments, but flow over grassy slopes between low banks. The sheets of water have not collected into well-defined channels.

The trail from Macas to Riobamba on the Andean plateau followed the Rio Upano to its source in lakes high in the Andes. The river is in a deep gorge on the eastern slope of the Andes, and, like the valley of the Pastaza, makes a natural route from the highlands into the Oriental region.

FORESTS

The forests are limited entirely to the lower slopes of the Andes and to the lowlands at the east. The highlands of the Andes, due to the lack of rainfall, are treeless and are called *paramos*. No breaks occur in the extensive forests east of the Andes except in the neighborhood of the small settlements where a few acres are cleared.

CLIMATE

The rainfall is exceptionally heavy on the east slope of the Andes, but light on the plateau. Its greatest amount occurs on the immediate east wall of the mountains, where the moisture-laden air begins to ascend. What precipitation reaches the lofty elevations of Chimborazo and other peaks which rise more than 20,000 feet above the sea occurs as snow and ice. Extensive glaciers and snow fields are located on Antisana, Chimborazo, and other peaks. The snow line is about 15,000 feet above sea-level. The rainfall at Puyo at the eastern base of the Andes, at an elevation of 3,200 feet, has been estimated at 150 inches per year.

In the area explored east of the Andes between elevations of 1,400 and 2,000 feet the temperature ranged from 66° to 82° Fahrenheit.

INHABITANTS

The Andean plateau is well populated; the Amazon lowlands have very few inhabitants. The Indian aborigines east of the Andes form the main part of the population. The Indians north of the Pastaza live close to the few white settlements and speak the Quechua language. South of the Pastaza dwell Indians who are entirely independent of white masters and speak the Jivaro language. The latter are noted for their head-hunting customs, which have been described by several writers.[1]

SETTLEMENTS

Settlements in the Oriente are few and located along streams, which are the chief means of communication. The settlements consist of a few white families who have the loyalty and service of many Indians living close by. At Napo there are four houses inhabited by white Spanish-speaking people, among whom is Manuel Rivadeneyra, a true pioneer. It was once a mission station with a larger population. Tena, 4 miles north of Napo, is somewhat larger, since it is the headquarters of the governor of the Oriente. Archidona, near Tena, was founded soon after the Spanish conquerors arrived in Ecuador and became the headquarters of the early missionaries. Canelos is the principal settlement between the Napo and the Pastaza. It was also founded as a Catholic mission shortly after the Spanish conquest of Ecuador. Today, after several periods of abandonment, it is again a mission center with two Dominican fathers in charge. Macas, located in the southern part of the area, is much the largest town in the Oriente, having a population of about 600. In 1921 it had a Protestant mission in charge of Mr. and Mrs. Oleson, and a Catholic mission. The village of Macas is so isolated, one wonders at its existence. There is no other settlement between it and the top of the Andes. It takes seven days of tedious traveling on foot along muddy trails to reach the nearest settlement on the upland.

The Indians have no villages as such. The Jivaros approach more closely a social organization in that sometimes they live in large houses containing several families.

STRATIGRAPHY

ANDEAN CRYSTALLINE ROCKS

The trail down the Pastaza from Ambato to Baños passes through a region of recent volcanic activity, and most of the surface exposures are made up of extrusive material. Near Pelileo some rhyolite was observed.

[1] F. W. Up De Graff, *The Head Hunters of the Amazon* (New York, 1923), 337 pages.

From the junction of the Chambo and Patate to Baños the south wall of the Pastaza canyon is made up of lava flows from the volcano Tunguragua. In some places basaltic columnar structure is well developed. Schists, gneisses, and granites are exposed along the north side of the river above Baños to Mera. Granites and rhyolites occur above Mera. These rocks, which form the core of the Andes of Ecuador, were not studied in detail. They are unquestionably older than the sedimentary series east of the mountains.

NAPO REGION—SEDIMENTARY SECTION

The best sedimentary section exposed in the area is in the vicinity of Napo. The beds outcrop in an area whose dimensions are 25 miles north and south by 10 miles east and west, and whose elevations range from 1,500 to 2,000 feet. The outcrops are along streams where the forest cover has been cut away by stream action. In the absence of any geological information on the region, notes were taken on all rocks examined and collections of fossils were made. As the work progressed it was possible to make up a column and determine age and extent of beds.

MISAHUALLI BASALTS AND TUFFS

The lowest rocks observed in the Napo region are on the Rio Misahualli, 6 miles east of Tena. They consist of basalts and altered extrusive igneous rocks overlain by tuffs. The basalt is predominantly green or dark brown, and in its altered condition has the appearance of sedimentary rock. The greatest thickness observed is about 150 feet. These igneous extrusives probably represent local flows interbedded with the sediments. The tuffs overlying the basalt are gray and pink in color and are in sharp contrast to the overlying sandstone. The thickness was not determined, but it is probably not more than 100 feet.

HOLLIN SANDSTONE

Overlying the basalts and tuffs of the Rio Misahualli is a clean, fine-grained quartz sandstone with a thickness of 400 feet. It is well exposed along the Rio Hollin, where cliffs more than 100 feet high are found. No basal conglomerate was found at the contact with the underlying igneous rocks; neither was there any inclusion of igneous material in the overlying sandstone. Near the confluence of the Rio Tena and the Rio Hollin is a thin bed of unfossiliferous black shale near the middle of the sandstone. The exposures of Hollin sandstone are near the axis of the Napo anticline, where only basalts and tuffs were seen to underlie it. It is probable that the igneous rocks are local flows and that older sedimentary beds exist beneath them.

THE NAPO LIMESTONE

Overlying the Hollin sandstone is a series of limestones and black shales 1,500 feet thick. The forest cover makes the estimation of thickness very difficult. The best section of these beds exposed in the area is along the Rio Napo eastward from the town of Napo. From the crest of the low anticline just west of the town beds of limestone and shale dip 6°–10° E. The strike is N. 45° E. At some places the Rio Napo flows along the strike of the beds. A thick limestone member outcrops from the crest of the anticline just west of Napo to a point one mile downstream (Fig. 2), where black shales are found overlying it. This limestone is dark gray and highly fossiliferous, at places being almost a shell conglomerate. It weathers into large blocks. The lower beds merge into a shale which is exposed at low water on the anticlinal axis just west of Napo. Here a bone bed is found carrying fish vertebrae and teeth along with ammonites. This bone bed is the lowest exposure in the Rio Napo section. The black shales carry many fossils, the most prominent being *Inoceramus labiatus*. Flat lens-like inclusions of limestone are in the upper layers of this shale. The highest Napo limestone beds are 6 miles below Napo, at the rapids called Molino de Latas. Here they dip into the river and a short distance downstream they are covered by red beds.

Other sections of the Napo limestone were studied north of Napo (Fig. 3). The contact of the Napo limestone with the underlying Hollin sandstone is seen about 5 miles east of Tena, along the Rio Tena and along the Rio Hollin east of Archidona. The black shales are also exposed east of Tena. The section along the Rio Tena is on the west flank of the anticlinal axis, which passes just west of the town of Napo.

The age of the Napo limestone has been determined, from the fossils collected, as middle Comanchean to Upper Cretaceous, middle Albion to Turonian of the European section. These fossils are largely of Turonian age, equivalent in the United States to Eagle Ford or Benton of the Texas and Rocky Mountain sections, respectively. John B. Reeside, Jr., who examined these fossils, called attention to Albian forms comparable to the mid-Comanchean or Fredericksburg of Texas occurring below the Turonian without any evidence of Cenomanian between. It is possible that Cenomanian beds exist, but that no fossils were collected from them.

The best Albian fossils came from the Rio Hollin, east of Archidona, from beds just above the Hollin sandstone. The Napo beds all yield Turonian forms, the highest Turonian coming from limestone beds east of Morales' house on the trail from Archidona to Quito. A collection of

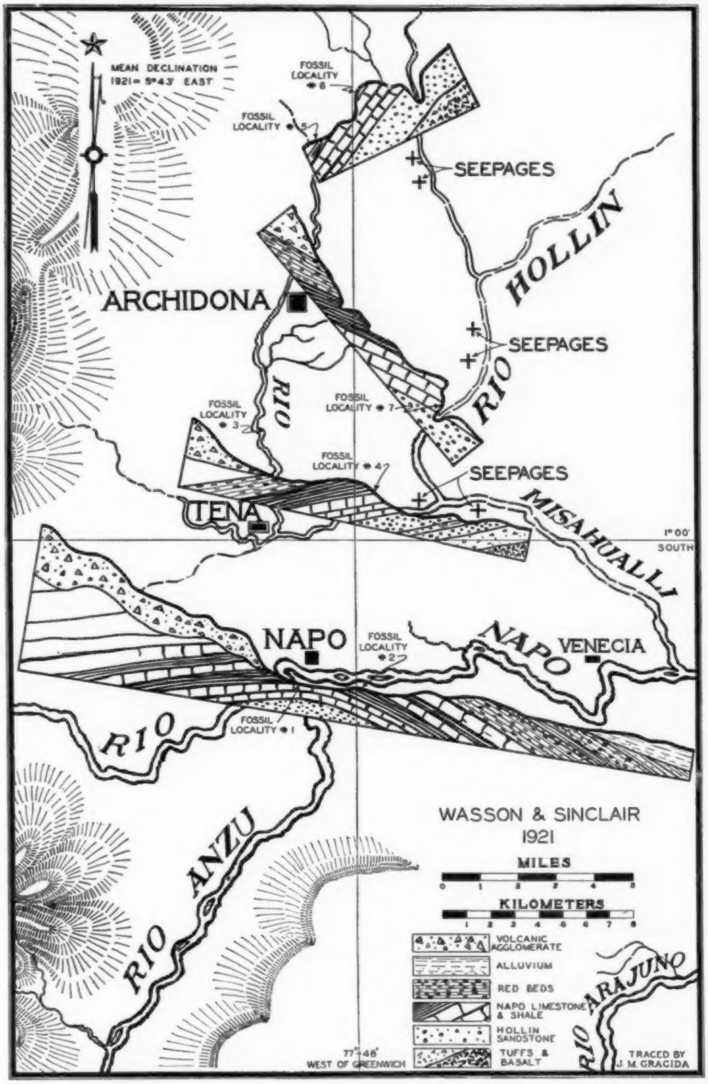

FIG. 2.—Map of the Napo area showing sections of the Napo limestone, fossil localities, and seepages.

fossils from the trail crossing Ursuyacu Creek, $9\frac{1}{2}$ miles north of Napo, shows Albian forms, but field evidence was lacking to show the relation of the highly tilted shales of this locality to the rocks of the Napo and Archi-

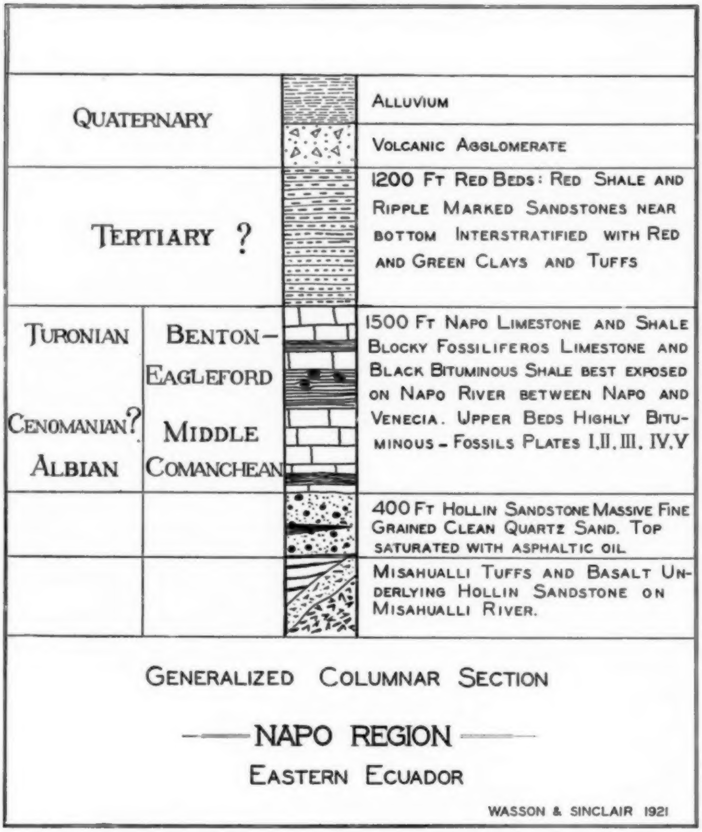

FIG. 3.—Refer to Plates 9, 10, 11, 12, and 13 for fossils.

dona areas. Further work in the region may make it possible to divide the Napo limestone into separate formations. For the purposes of this first report the Napo limestone is understood to represent the limestones and black shales which lie between the sandstone of the Rio Hollin and the red beds at Venecia on the Rio Napo. It is interesting to note that

James Orton[1] referred to the Napo rocks as "dark slates gently dipping east," and made no mention of the Cretaceous fossils (Fig. 4).

Fossil localities.—Fossils of the Napo limestone were collected from the following eight localities (Fig. 2):

1. An outcrop of shales and limestones on the left bank of the Rio Napo about ¼ mile above the village of Napo at the crest of the broad anticline, where the strata are nearly flat and unquestionably in place.

FIG. 4.—Napo limestone dipping downstream, located on the bank of Rio Napo

2. Left bank of the Rio Napo, 1 mile below the village of Napo, from black shales and limestones in place and striking N. 45° E. and dipping 8° SE.

3. The Rio Misahualli, about 2 miles above its confluence with the Rio Tena.

4. In the Rio Misahualli, between the mouth of the Rio Tena and the mouth of the Rio Hollin, where black shales and limestones occur partly in place and as great blocks fallen down into the narrow canyon from the cliff walls.

5. Trail leading east from the Quito road at the house of José Morales, north of Archidona, to the Rio Jandachi (locality 6). The specimens were from a yellow sandy horizon near the top of the Napo limestones. Locality is 1¾ miles northeast of Morales' house.

[1] James Orton, *The Andes and the Amazon* (New York: Harper Brothers, 1870), p. 199.

6. Rio Jandachi, six miles northeast of Archidona in a narrow canyon with vertical cliff walls. Horizon should be near the base of the Napo limestones as the underlying sandstones form cliffs at the water surface.

7. Rio Hollin, 3 miles southeast of Archidona, about ½ mile below a seepage of tar in the river bed at the base of a cliff. At this locality the canyon is very narrow with nearly perpendicular walls. The blocks of limestone from which collections were made represent horizons in the cliffs.

8. Quito trail at the crossing of Ursuyacu Creek, 9½ miles north of Archidona.

REPORT ON THE FOSSILS

John B. Reeside, Jr., of the U. S. Geological Survey, examined the fossils collected and made the following report, accompanied by the illustrations shown in the succeeding plates. The fossils examined are deposited in the U. S. National Museum at Washington.

This collection of fossils contains a good representation of two very distinct Cretaceous faunas, one of Turonian age and one of middle Albian. The Turonian fauna in turn is represented by what I take to be two facies, for while the species and the matrix differ, the age is not very different.

The fauna in a hard limestone from the vicinity of the village of Napo (Fig. 2, localities 1 and 2) is composed of species universally accepted as characteristic of the Turonian, equivalent in a general way to that of the Eagle Ford shales of the Gulf region and the Benton formation of the western interior of North America. A very similar fauna is known from Peru, Colombia, and Venezuela.

The fossils in the hard gray limestone from the localities on Rio Misahualli (localities 3 and 4) include Albian and probably Turonian.

The small lots in gray limestone from Rio Jandachi I believe to be Turonian.

The large lot in a yellow sandy matrix that looks like a leached calcareous rock, from the locality on the trail east of the house of José Morales (locality 5), I judge also to be Turonian. There are several species present whose closest relationships are with characteristic Turonian forms, though a few have close relations with Cenomanian or Senonian species. Others are long-ranging and not definite in their testimony. The lot has only one species in common with those from the vicinity of Napo and differs much in lithology, but there can hardly be any great difference in age.

The lots from Rio Hollin southeast of Archidona (locality 7), are mostly in a dark-gray hard limestone and contain chiefly species universally accepted as characteristic of the Albian, particularly the ammonites. Some authors have called this fauna Vraconian, or late Albian, but Vraconian is better restricted to the very latest zones of the Albian. The genera *Brancoceras* and *Oxytropidoceras* are middle Albian. *Oxytropidoceras* is found in the Fredericksburg group of Texas. There are, however, also several specimens of black shale and gray limestone with characteristic Turonian species, showing that both the

Albian and Turonian horizons are present in the section. The Albian zone is equivalent to some part of the middle Comanchean of the Gulf region of North America, and its fauna is well known at many localities in Peru and Colombia.

The lot from Ursuyacu Creek at the crossing of the Quito-Napo road (locality 8) appears to be Albian, though I do not feel certain of the age in view of the absence of the more distinctive species.

The lot without specific locality assignments contains both Turonian and Albian species.

As these statements indicate, the Napo limestone series includes at least two very distinct elements: one of Turonian age and one of Albian age. Between them should lie any deposits representing Cenomanian time. Some of the fossils included in the lists are known in the Cenomanian; some of them, indeed, are used, at least locally, as diagnostic of it. Most of these species, however, have been identified through a considerable stratigraphic range when their entire geographic distribution is taken into account, and are therefore of doubtful value here. I do not see any clear evidence of the presence of a Cenomanian fauna in the collection in hand, though it might very well be represented in the Napo limestone, and through the unavoidable accidents of collecting not have found its way into the collections.

It is notable that the succession of beds in eastern Ecuador is much like that reported from central Peru. Schlagintweit[1] cites a generalized section in which light-colored marly limestone assigned to the Albian is overlain by a considerable thickness of dark limestone and marl assigned to the Vraconian, overlain in turn by a series of red and yellow crumbly shale and marls with beds of limestone assigned to the Upper Cenomanian. The Albian fauna has much in common with that noted in the present collections. The Upper Cenomanian appears to have a number of species in common with the Turonian fauna listed below from the locality east of José Morales' house, and is very probably of the same age. It is worthy of note that some of the age assignments made in the literature dealing with South American geology are not well warranted by the fossils on which they are based. These fossils have received names originally applied to European and African species, and while the similarity is usually great, I doubt the validity of carrying most of the names so far afield and basing overpositive age assignments upon them. The confusion thus made possible is shown by Berry[2] in discussing the fauna from a single bed near Huancavelica, Peru, where there occur together fossils previously assigned to European and African species of Aptian, Albian, Cenomanian, and Emscherian age.

The following lists give the species found in the various lots as designated by the accompanying labels:

[1] Otto Schlagintweit, "Die Fauna des Vracon und Cenoman in Peru," *Neues Jahrbuch.*, Beilageb. 33 (1911), pp. 48, 65.

[2] E. W. Berry and J. T. Singewald, Jr., "The Geology and Paleontology of the Huancavelica Mercury District," *Johns Hopkins University Studies in Geology*, No. 2 (1922), pp. 54–56.

1. Left bank of Rio Napo, ¼ mile above the village of Napo at crest of anticline:
   Inoceramus sp. indeterminable.
   Cyprimeria n. sp. aff. *C. excavata* Morton (Pl. 10, Figs. 4–6).
   Coelopoceras n. sp. A. aff. *C. lesseli* Brüggen and *C. springeri* Hyatt (Pl. 9, Figs. 1, 2).
   Coelopoceras sp. undetermined.
1. Napo, near house of Señor Rivadeneyra:
   Inoceramus labiatus Schlotheim.
   Cyprimeria n. sp. aff. *C. excavata* Morton.
2. Left bank of Rio Napo, 1 mile below village of Napo:
   Inoceramus labiatus Schlotheim (Pl. 10, Fig. 1).
   Roudairia intermedia Brüggen (Pl. 10, Figs. 2, 3).
   The fauna above from localities on Rio Napo is Turonian.
3. Rio Misahualli, 2 miles above confluence with Rio Tena:
   Oxytropidoceras (*Manuaniceras?*) *carbonarium* (Gabb) (=*Schloenbachia acutocarinata* Shumard of many authors).
   Middle Albian.
4. Rio Misahualli, between mouth of Rio Tena and Mouth of Rio Hollin.
   Exogyra aff. *E. flabellata* D'Orbigny (Pl. 10, Fig. 12).
   Pecten sp. indeterminable.
   Probably Turonian.
4. Rio Misahualli, below Tena.
   Probably Turonian species.
      Exogyra aff. *E. flabellata* D'Orbigny.
      Pecten (*Neithea*) *quinquecostata* Sowerby.
   Middle Albian species.
      Oxytropidoceras (*Manuaniceras?*) *carbonarium* (Gabb) (=*Schloenbachia acutocarinata* Shumard of many authors).
5. Trail to Rio Jandachi, 1¼ miles east of José Morales' house, which is 4 miles north of Archidona on the Quito-Napo road:

TURONIAN SPECIES

Arca n. sp. aff. *A. archiacana* D'Orbigny (Pl. 10, Fig. 13).
Glycimeris n. sp. (Pl. 10, Fig. 14).
Pinna sp. indeterminable (Pl. 10, Fig. 15).
Gervillia sp. indeterminable (Pl. 10, Fig. 16).
Pteria n. sp. aff. *P. gastrodes* Meek (Pl. 10, Figs. 17, 18).
Exogyra olisiponensis Sharpe (Pl. 11, Figs 1–3).
Exogyra aff. *E. flabellata* D'Orbigny (Pl. 11, Fig. 4).
Trigonia crenulata var. *peruana* Paulcke (Pl. 11, Figs. 5, 6).
Trigonia aff. *T. hondaana* Lea (Pl. 11, Fig. 7).
Pecten (*Neithea*) *aequicostata* Lamarck (Pl. 11, Fig. 8).
Pecten (*Syncyclonema*) n. sp. (Pl. 11, Fig. 9).
Plicatula aff. *P. auressensis* Coquand (Pl. 11, Fig. 10).

Lima? sp. indeterminable.
Modiola aff. *M. socorrina* D'Orbigny (Pl. 11, Figs. 11, 12).
Modiola n. sp. aff. *M. flichei* Peron (Pl. 11, Fig. 13).
Liopistha n. sp. aff. *L. ligeriensis* D'Orbigny (Pl. 11, Figs. 14, 15).
Cardita n. sp. aff. *C. subparallela* Gerhardt (Pl. 11, Figs. 16, 17).
Protocardia appressa Gabb. (Pl. 11, Fig. 18).
Venus n. sp. (Pl. 11, Figs. 19, 20).
Tellina? sp. indeterminable (Pl. 11, Fig. 21).
Mactra? n. sp. (Pl. 12, Fig. 1).
Corbula cf. *C. peruana* Gabb (Pl. 12, Figs. 2, 3).
Gyrodes n. sp. aff. *G. depressa* Meek (Pl. 12, Figs. 4, 5).
Turritella aff. *T. vibrayeana* D'Orbigny (Pl. 12, Fig. 6).
Aporrhais aff. *A. costae* Choffat (Pl. 12, Fig. 7).
Aporrhais sp. indeterminable.
Fusus n. sp. aff. *F. ubaquensis* Gerhardt (Pl. 12, Fig. 8).
Mammites n. sp. (=*Mortoniceras cañaense* Gerhardt?) Pl. 12, Figs. 9–11).

6. Rio Jandachi, 3 miles east of José Morales' house, which is 4 miles north of Archidona on Quito-Napo road:
Astarte sieversi Gerhardt
Exogyra aff. *E. flabellata* D'Orbigny (Pl. 10, Fig. 11).
Probably Turonian.

7. Five miles southeast of Archidona:

MIDDLE ALBIAN SPECIES

Inoceramus concentricus Parkinson (Pl. 12, Figs. 12, 13).
Ostrea sp. indeterminable.
Plicatula aff. P. *gurgitis* Pictet and Roux (Pl. 12, Fig. 14).
Brancoceras n. sp. (Pl. 12, Figs. 15–17).
Oxytropidoceras (*Manuaniceras?*) *carbonarium* (Gabb) (=*Schloenbachia acutocarinata* Shumard of many authors) (Pl. 12, Figs. 18–20.)
Oxytropidoceras n. sp. aff. *O. belknapi* (Marcou) (Pl. 13, Figs. 1, 2).

TURONIAN SPECIES

Inoceramus labiatus Schlotheim.
Cyprimeria n. sp. aff. *C. excavata* Morton.
Exogyra olisiponensis Sharpe.
Coelopoceras n. sp. B. (Pl. 9, Figs. 3–5).

8. Ursuyacu Creek at crossing of Quito-Napo road, between abandoned house of Manuel Lara and the crossing of Rio Jandachi. About 9½ miles north of Archidona:
Exogyra aff. *E. africana* Coquand (Pl. 13, Figs. 3, 4).
Pecten (*Neithea*) n. sp. aff. *P. phaseola* Lamarck (Pl. 13, Fig. 5).
Pecten n. sp. aff. *P. marrotianus* D'Orbigny (Pl. 13, Fig. 6).
Lima n. sp. (Pl. 13, Figs. 7, 8).

Plicatula aff. *P. gurgitis* Pictet and Roux (Pl. 13, Fig. 9).

This fauna appears to me to be Albian, though not conclusive as to age.

8. East of Andes between Rio Napo and Cordillera Guacamayos:

ALBIAN SPECIES

Inoceramus concentricus Parkinson (Pl. 13, Fig. 12).
Ostrea syphax Coquand (Pl. 13, Figs. 13, 14).
Lima n. sp. aff. L. intermedia D'Orbigny (Pl. 13, Figs. 10, 11).
Brancoceras n. sp. same as at locality 7.
Oxytropidoceras (*Manuaniceras?*) *carbonarium* (Gabb) (=*Schloenbachia acutocarinata* Shumard of many authors).

TURONIAN SPECIES

Inoceramus labiatus Schlotheim (Pl. 10, Fig. 7).
Inoceramus sp. indeterminable (Pl. 10, Fig. 8).
Pecten quinquecostata Sowerby (Pl. 10, Figs. 9, 10).

UNASSIGNED SPECIES

Pholadomya? sp. indeterminable.
Venerid pelecypod, indeterminable.
Gastropod, indeterminable.

RED BEDS AND CONGLOMERATES

Overlying the Napo limestone are red beds and conglomerates which extend in a belt from north to south across the area explored. A contact between the Napo limestone and the red beds is well exposed at Venecia, 7 miles east of Napo. Although the bedding appears conformable, the abrupt change from hard, fossiliferous limestone to soft, red sandstones and shales is very marked and may represent an unconformity of some magnitude. No fossils were found in the red shales. The dip is eastward at angles of 6°–10°. Eastward from Venecia the river clays and sands cover these beds in a short distance. West of Napo glimpses of the red beds are seen on the west limb of the Napo anticline. They are here obscured by the overlying volcanic agglomerate. In the vicinity of Tena and Archidona remnants of the red clays are found on the west side of the Napo structure. The thickness of red beds exposed is not great, being about 1,200 feet at Venecia, but the overlapping alluvium probably obscures a much thicker section. South of Napo, near the headwaters of the Rio Arajuno and Rio Curaray, the red beds grade upward into cross-bedded sandstones and conglomerates which carry lignitic wood and cannon-ball concretions. What appears to be the contact of the conglomerates with the red clays was observed on the Rio Anzu', 4 miles south of Napo. These conglomerates may represent local phases of the red beds,

and for the purposes of this report will be grouped with them, as no fossils were found which would indicate their age.

West of the belt of outcrop the red beds are overlain by volcanic material, and to the east they are covered by alluvium. The age of these red beds is one of the unsolved problems of this region. They are tentatively grouped as Tertiary.

James Orton[1] made no direct reference to red beds close to the village of Napo, but did mention clay deposits interstratified with lignites which he found at the mouth of the Curaray and at Pebas, 300 miles farther east. Orton referred to his Pebas beds (map, Fig. 1) as of not later than Pliocene age, but it is doubtful whether they can be correlated with the sandstones and conglomerates of the Napo region on the strength of lignitic layers alone.

Red beds of Oligocene age have been identified east of the Andes in Peru. A fragment of a jawbone with well-preserved teeth from the salt gypsum beds which lie above the limestones was found by J. G. Richards at Chiococa, near Chepeza, on Rio Huallaga, Peru, which is 250 miles south of Napo.[2] This was examined by H. E. Anthony.[3] He describes the fossil teeth as those of a tapiroid animal which lived in Oligocene time.

VOLCANIC AGGLOMERATE

Beds of volcanic débris overlie the Napo rocks, in many places obscuring all exposures. This is particularly true in the belt close to the base of the Andes. These volcanic beds are made up of poorly assorted, angular, volcanic fragments among which are round lapillae and bombs.

[1] James Orton, *The Andes and the Amazon* (New York: Harper Brothers, 1870), p. 282. "We came down the Napo and Marañon, and stopped at this place [Pebas]. Here we discovered a fossiliferous bed intercalated between the variegated clays so peculiar to the Amazon. It was crowded with marine Tertiary shells! . . . . It was unmistakable proof that the formation was not drift but Tertiary; not of fresh but of salt water origin.

"The species as determined by W. M. Gabb, Esq., of Philadelphia, are: *Neritina pupa, Turbonilla minuscula, Mesalia ortoni, Tellina amazonensis, Pachydon oblique* and *P. tunua.* All of these are new forms, excepting the first, and the last is a new genus. It is a singular fact that the Neritina is now living in the West India waters, and the species found at Pebas retains its peculiar markings. . . . . Interstratified with the clay deposits are seams of highly bituminous lignite; we traced it from the mouth of the Curaray on the Rio Napo to Loreto on the Marañon, a distance of about 400 miles. It occurs also at Iquitos."

[2] J. G. Richards, *Expedition on the Amazon for the Pure Oil Co.*, 1920.

[3] H. E. Anthony, "A New Fossil Perissodactyl from Peru," *American Museum Novitates No. 111*, Op. 21 (New York: American Museum of Natural History, 1924).

Mud flows and landslides frequently occur in these beds. The western half of the area explored, particularly the portion east of the volcano Sangay, is covered with these volcanic agglomerates which in age probably range from late Tertiary to Recent.

STRUCTURE

The great fault which forms the east scarp of the Andes is the major structural feature of this region. Its throw can be roughly estimated by comparing the Cretaceous rocks reported in the mountains at elevations of 10,000 feet or more with those at Napo, which are at an elevation of 2,000 feet. The fault zone is obscured by extrusive volcanic material. The regional dip of the sedimentary rocks in the Oriental region is eastward away from the mountains. Near the mountains the beds dip westward into the fault. This reversal of dip gives rise to anticlinal structures which lie parallel to the mountains.

THE NAPO ANTICLINE

The axis of the Napo anticline lies just west of the town of Napo. The reversal of dip is well shown in black shales and limestones which are exposed along the river. The west dip is 6°–10°, the east dip about the same. The axis of this anticline strikes N. 45° E., passing east of Tena and crossing the Rio Misahualli just east of the mouth of the Rio Hollin. Farther northeast it probably becomes a part of the Galeras mountain uplift, which was not explored. The plunge of the Napo anticline to the southwest is shown by the existence of the Hollin sandstone on the surface near the mouth of the Rio Hollin, while along the Rio Napo it is overlain by several hundred feet of limestone and shale. The axis of the Napo anticline projected southwestward follows the valley of the Rio Anzú. This valley is probably anticlinal throughout its length.

MIRADOR UPLIFT

In the Mirador hills northeast of Mera and near the headwaters of the Rio Anzú a mass of dark gray limestone resembling the Napo beds and lying at elevations above 4,000 feet suggests an uplift in this area. These beds appear to be nearly horizontal. A sink-hole type of topography has developed on the limestone outcrops. Fossils collected were thrown away by the Indian carriers when they discovered their pack baskets contained rocks. Remnants of red beds capping some of the hills indicate that these limestones are equivalent to those west of Venecia on the Rio Napo.

FAULTING NORTH OF CANELOS

A zone of faulting extends from the headwaters of the Rio Curaray nearly to Canelos, a distance of 30 miles. The best evidence was found in the high ridge between the Rio Curaray and the Rio Villano. The downthrow side is to the east. Beds of lignitic conglomerate are faulted against the red beds. The amount of displacement could not be determined accurately. Some local exposures showed a throw of 150 feet. This fault zone is 25 miles east of the Mirador uplift and may be the eastern escarpment of the high land which extends eastward from the Mirador.

SYNCLINE ALONG THE RIO ARAJUNO

Where the trail from Napo to Canelos crosses the Rio Arajuno there is a syncline in the red beds. It was not followed for any distance, but its position seems to indicate that it follows the course of the Rio Arajuno which flows into the Napo about 10 miles below Venecia. This syncline, with an axis roughly parallel to the Napo anticline, suggests the existence of another anticline southeast of the Napo between that river and the Rio Curaray in an area which was not explored.

EAST OF ALAPICOS

Rock specimens brought from the confluence of the Rio Palora and Rio Pastaza by the Indians resembled the petroliferous limestones at Napo, but the high water in the Rio Palora prevented a visit to those outcrops. They are mentioned as being from a possible uplift similar to that at Napo and Mirador, where the underlying limestones have been exposed by the erosion of the red beds.

EVIDENCE OF PETROLEUM

The Napo limestone is found to be more or less petroliferous. Along the Rio Napo the limestones and black shales are in many places impregnated with asphaltic oil. Small quantities of black oil seep from cavities and bedding planes of the upper Napo limestone east of El Molino de Latas. On the axis of the Napo anticline just west of the settlement of Napo gas escapes from the black shales and can be observed at low water on the north side of the stream. Petroliferous limestones occur in the Mirador uplift and in the area east of Alapicos.

The Hollin sandstone also carries asphaltic material. On the Rio Misahualli near the mouth of the Rio Hollin there are seepages of asphaltic oil from the Hollin sandstone which outcrops on the axis of the Napo anticline. These seepages are from the lower half of the sandstone. The seepage oil occurs with sulphur water and forms pools 10–15 feet

across. There is some evidence of natural gas. The upper beds of the Hollin sandstone exposed along the Rio Misahualli are stained with asphaltic oil. East of Archidona the Rio Hollin and its tributary, the Rio Jandachi, cut across the west limb of the Napo anticline and have exposed the Hollin sandstone in their canyon walls. Seepages occur from the oil-saturated sandstone, but the nearly vertical walls have prevented any great accumulation. This oil-bearing sandstone extends for several miles. Its northern limits were not determined.

COMPARISON WITH OTHER AREAS

The oil-bearing beds at Napo may be compared to the Colon shales and limestones of Upper Cretaceous age which occur along the west side of the Maracaibo Basin in Venezuela, 700 miles to the northward. Liddle[1] has measured sections showing a thickness of 3,500 feet of Colon shale overlying 1,000 feet of the upper part of the Lower Cretaceous which lies upon a basal Cretaceous conglomerate. The Colon shales are petroliferous and contain fossils similar to those of the Napo limestone. Along the west side of the Maracaibo Basin several large seepages occur from the upturned Colon beds.

In Colombia Anderson[2] has described the Villeta and Guadalupe beds of Middle to Upper Cretaceous age. Their thickness is similar to that measured on the Venezuelan side of the mountains. In the upper Magdalena Valley Garner[3] has referred to the thick bituminous shales in the Upper Cretaceous as being the probable source of much of the oil found there.

Joseph T. Singewald, Jr., recently announced the results of his observations on the Pongo de Manseriche on the upper course of the Amazon of eastern Peru.[4] He found a thick sandstone overlain by a Cretaceous shale and limestone series, above which are the red beds. This sequence agrees closely with that found in the Napo section, although his thicknesses are considerably greater.

Seepages extending 600 kilometers southward from the Province of Mendoza, Argentina, were found by Robert Anderson[5] to be from beds of

[1] R. A. Liddle, "The Geology of Venezuela and Trinidad" (manuscript for book).

[2] F. M. Anderson, "Original Source of Oil in Colombia," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 4 (April, 1926).

[3] A. H. Garner, "General Oil Geology of Colombia," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 2 (February, 1927), p. 153.

[4] J. T. Singewald, Jr., "The Pongo de Manseriche, Peru," paper presented before the Geological Society of America, Madison, Wisconsin, December, 1926.

[5] Robert Anderson, "Observations on the Occurrence and Origin of Petroleum in Argentina and Bolivia," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 9 (September, 1926), p. 857.

Jurassic and Lower Cretaceous age. They contain many marine fossils and are thought to be the source beds for the seepage oil.

ORIGIN OF THE OIL

The oil found in this area probably has its origin in the Napo limestone, which consists of highly fossiliferous marine limestones and shales of Cretaceous age found to be petroliferous wherever exposed. This oil in the upper beds of the Hollin sandstone may have migrated laterally from the Napo limestone, which is adjacent to it along the flanks of the Napo anticline. Seepages from the base of the Hollin sandstone suggest upward migration from organic beds not exposed.

Igneous intrusions may have played some part in the migration and accumulation of oil in other parts of the region, but in the Napo area, where the best evidences of oil were observed, intrusions have not been found. The oil-bearing rocks are relatively close to the eastern scarp of the Andes and are associated with volcanic flows, but have not suffered any great alteration.

PROSPECTS FOR OIL FIELDS

Geological work has been of a *reconnaissance* nature, all observations being limited to the vicinity of streams or along trails cut through the forest.

The evidence of petroleum found in the rocks of the Napo section leads to the conclusion that the Hollin sandstone has possibilities of production wherever proper depth and structural conditions exist.

Sandstones and shales in the lower part of the red beds may act as reservoirs for oil by migration upward from the uppermost Napo beds. Tertiary beds higher than those observed may also be oil-bearing under structures east of the Napo area.

The Rio Napo oil-bearing Cretaceous beds lying close to the eastern base of the Andes of Ecuador are another link in the chain of oil-bearing Cretaceous strata extending from Venezuela and Colombia to Argentina.

DISCUSSION

JOSEPH T. SINGEWALD, JR.: The Permian area south of Ecuador shows the same stratigraphic units as Ecuador. It differs in absence of volcanics and greater thickness of beds. The Hollin sandstone probably is the same as the coal-bearing quartzitic sandstone of the main Andes, which is lowermost Cretaceous or uppermost Jurassic. The Napo limestone-shale ranges from Albian to Coniacian in age. The red beds in Peru lie conformably on the Napo series, hence must be in part uppermost Cretaceous and may extend into the Tertiary. Overlying the red beds is a younger series of beds of considerable thickness. All of these strata participated in the orogenic movements of the eastern

Andes. In the Amazon Basin are flat-lying beds with a Pliocene brackish-water fauna, long known from collections made by Orton and other early explorers at the town of Pebas. The folding of the eastern Andes occurred probably in Miocene time. The red beds in Peru are sparingly fossiliferous, containing poorly preserved gastropods and a few pelecypods.

EXPLANATION OF PLATES

Plate 9

Figures 1, 2: *Coelopoceras* n. sp. A aff. *C. lesseli* Brüggen and *C. springeri* Hyatt. Side view and cross-section of an internal cast from left bank of Rio Napo, ½ mile above the village of Napo at crest of anticline.

Figures 3–5: *Coelopoceras* n. sp. B from Rio Hollin, 5 miles southeast of Archidona. Figures 3, 4: Side view and cross-section of an internal cast. Figure 5: Side view of another specimen retaining the shell.

All figures reduced one-seventh.

Plate 10

Turonian Fossils from Eastern Ecuador

Figure 1: *Inoceramus labiatus* Schlotheim. Side view of specimen flattened in shale, from Rio Napo, just below village of Napo.

Figures 2, 3: *Roudairia intermedia* Brüggen. Side and front views of specimen from left bank of Rio Napo, 1 mile below village of Napo.

Figures 4–6: *Cyprimeria* n. sp. aff. *C. excavata* Morton, from left bank of Rio Napo, ½ mile below village of Napo. Figures 4, 5: Side and cardinal view of a specimen. Figure 6: Cross-section of hinge of another specimen.

Figure 7: *Inoceramus labiatus* Schlotheim. Side view of specimen flattened in shale from region between Rio Napo and Cordillera Guacamayos.

Figure 8: *Inoceramus* sp. Side view of specimen from region between Rio Napo and Cordillera Guacamayos.

Figures 9, 10: *Pecten* (*Neithea*) *quinquecostatus* Sowerby from region between Rio Napo and Cordillera Guacamayos. Figure 9: View of right valve. Figure 10: View of left valve.

Figure 11: *Exogyra* aff. *E. flabellata* D'Orbigny. Side view of left valve from Rio Jandachi, 3 miles northeast of José Morales' house, which is on Quito-Napo road 4 miles north of Archidona.

Figure 12: *Exogyra* aff. *E. flabellata* D'Orbigny. Side view of left valve from Rio Misahualli between mouth of Rio Tena and mouth of Rio Hollin.

Figure 13: *Arca* n. sp. aff. *A. archiacana* D'Orbigny. Side view of internal cast from locality 1¼ miles east of house of José Morales, on trail leading east to Rio Jandachi. Morales' house is 4 miles north of Archidona on Quito-Napo road.

Figure 14: *Glycimeris* n. sp. Side view of internal cast from same locality as last.

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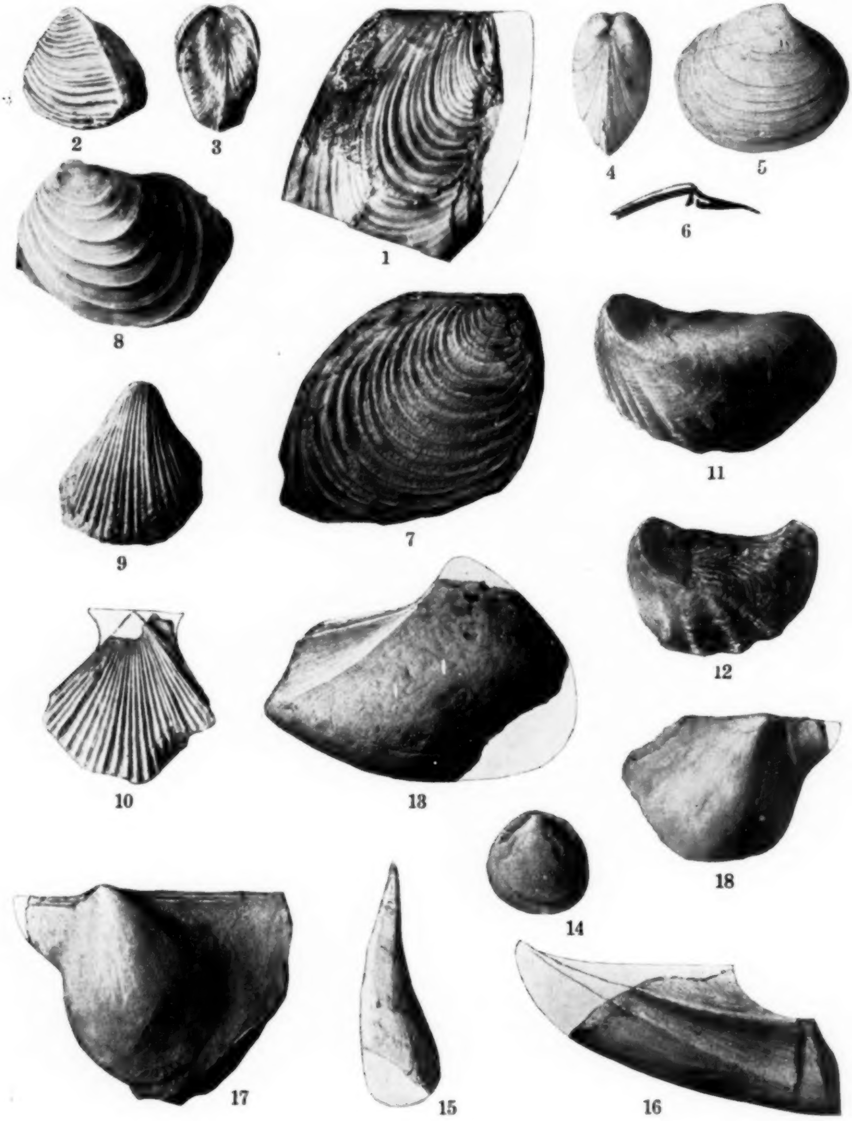
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Figure 15: *Pinna* sp. Side view of internal cast from same locality as last.

Figure 16: *Gervillia* sp. Side view of internal cast from same locality as last.

Figures 17, 18: *Pteria* n. sp. aff. *P. gastrodes* Meek, from same locality as last. Figure 17: Side view of an internal cast of a right valve. Figure 18: Side view of an internal cast of a left valve.

All figures reduced one-seventh.

Plate 11

Turonian Fossils from Eastern Ecuador

All specimens shown on this plate are from locality 1¼ miles east of José Morales' house on trail leading east to Rio Jandachi. Morales' house is 4 miles north of Archidona.

Figures 1–3: *Exogyra olisiponensis* Sharpe. Figures 1, 2: Top and side views of natural mold of interior of large (left) valve. Figure 3: View of plaster cast from natural mold of exterior of small (right) valve, somewhat enlarged.

Figure 4: *Exogyra* aff. *E. flabellata* D'Orbigny. Side view of internal cast of left valve.

Figures 5, 6: *Trigonia crenulata* var. *peruana* Paulcke. Side and cardinal views of internal cast.

Figure 7: *Trigonia* aff. *T. hondaana* Lea. Side view of internal cast.

Figure 8: *Pecten* (*Neithea*) *aequicostatus* Lamarck. Side view of internal cast.

Figure 9: *Pecten* (*Syncyclonema*) n. sp. Side view of internal cast of part of valve.

Figure 10: *Plicatula* aff. *P. auressensis* Coquand. View of squeeze from mold of surface of part of valve.

Figures 11, 12: *Modiola* aff. *M. socorrina* D'Orbigny. Figure 12: View of squeeze from mold of exterior of left valve. Figure 11: View of internal cast of right valve.

Figure 13: *Modiola* n. sp. aff. *M. flichei* Peron. Side view of internal cast.

Figures 14, 15: *Liopistha* n. sp. aff. *L. ligeriensis* D'Orbigny. Side and cardinal views of internal cast of nearly complete shell.

Figures 16, 17: *Cardita* n. sp. aff. *C subparallela* Gerhardt. Side and front views of internal cast.

Figure 18: *Protocardia appressa* Gabb. Side view of internal cast.

Figures 19, 20: *Venus* n. sp. Figure 19: Side view of internal cast of right valve. Figure 20: View (× 4) of squeeze of hinge.

Figure 21: *Tellina?* sp. indeterminable. Side view of internal cast.

All figures except figure 20 reduced one-seventh.

Plate 12

Turonian and Albian Fossils from Eastern Ecuador

Turonian Fossils

Figure 1: *Mactra?* n. sp. Side view of internal cast from locality 1¼ miles east of José Morales' house, on trail leading east to Rio Jandachi. Morales' house is 4 miles north of Archidona.

Figures 2, 3: *Corbula* aff. C. *peruana* Gabb. Side and cardinal views of an internal cast from same locality as last.

Figures 4, 5: *Gyrodes* n. sp. aff. *G. depressa* Meek. Two views of an internal cast from same locality as last.

Figure 6: *Turritella* aff. *T. vibrayeana* D'Orbigny. View (×2) of fragment from same locality as last.

Figure 7: *Aporrhais* aff. *A. costae* Choffat. View of internal cast from same locality as last.

Figure 8: "*Fusus*" n. sp. aff. *F. ubaquensis* Gerhardt. View of an internal cast from same locality as last.

Figures 9–11: *Mammites* n. sp. (=*Mortoniceras cañaense* Gerhardt?). Same locality as last. Figures 9, 10: Side and back view of internal cast. Figure 11: View of plaster cast from mold of exterior of same specimen.

Albian Fossils

Figures 12, 13: *Inoceramus concentricus* Parkinson. Side and front views of an internal cast from Rio Hollin, 5 miles southeast of Archidona.

Figure 14: *Plicatula* aff. *P. gurgitis* Pictet and Roux. View of an internal cast from same locality as last.

Figures 15–17: *Brancoceras* n. sp. From same locality as last. Figures 16, 17: Side and siphonal views of internal cast. Figure 15: Suture of another specimen.

Figures 18–20: *Oxytropidoceras* (*Manuaniceras?*) *carbonarium* (Gabb) (=*Schloenbachia acutocarinata* Shumard of many authors). Side and siphonal views and suture (×2) of specimen from same locality as last.

All figures except figures 6 and 18 reduced one-seventh.

Plate 13

Albian Fossils from Eastern Ecuador

Figures 1, 2: *Oxytropidoceras* n. sp. aff. *O. belknapi* (Marcou). Side view and cross-section of only specimen, an internal cast retaining fragments of the shell, from Rio Hollin, 5 miles southeast of Archidona.

Probably Albian Fossils

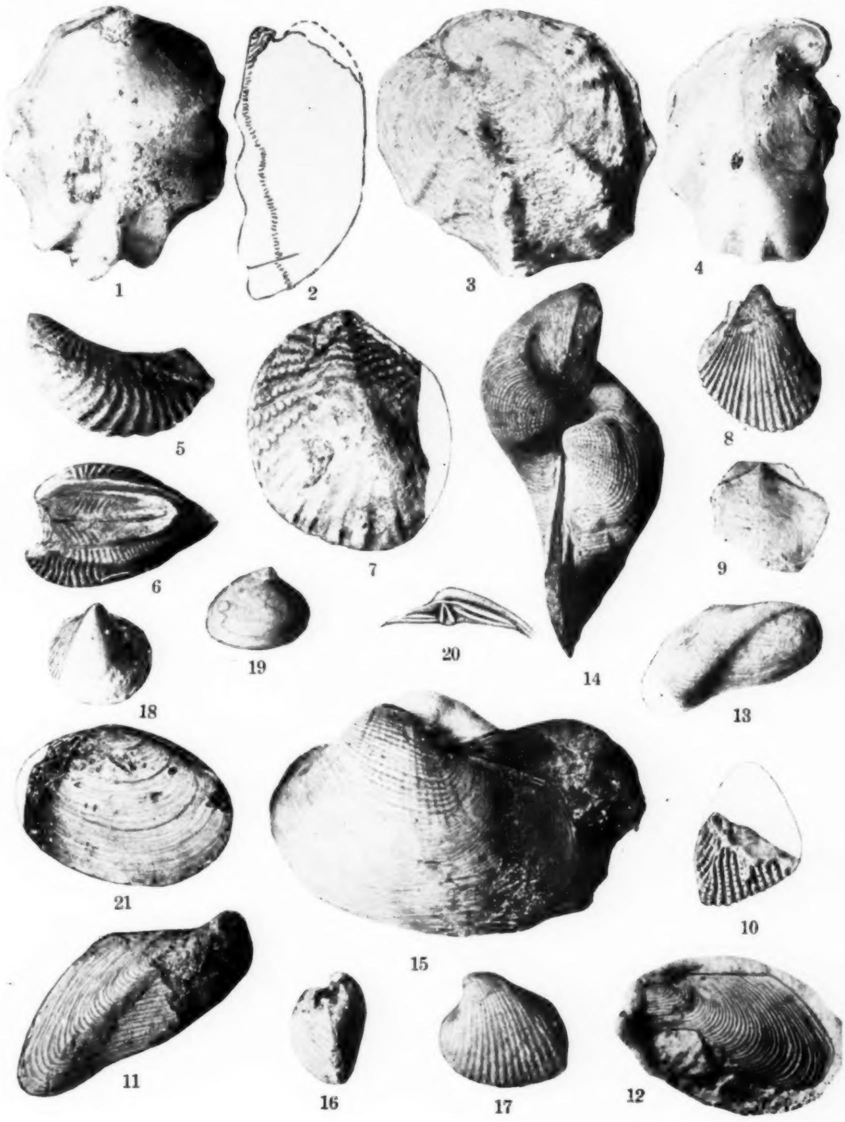
Figures 3, 4: *Exogyra* aff. E. *africana* Coquand. Side and front views of an internal cast from Ursuyacu at crossing of Quito-Napo road, about 9½ miles north of Archidona.

Figure 5: *Pecten* (*Neithea*) n. sp. aff. *P. phaseola* Lamarck. View of only specimen, from same locality as last.

Figure 6: *Pecten* n. sp. aff. *P. marrotianus* D'Orbigny. View of only specimen, from same locality as last.

Figures 7, 8: *Lima* n. sp. View of only specimen and part of surface (×4) from same locality as last.

Figure 9: *Plicatula* aff. *P. gurgitis* Pictet and Roux. View of a specimen from same locality as last.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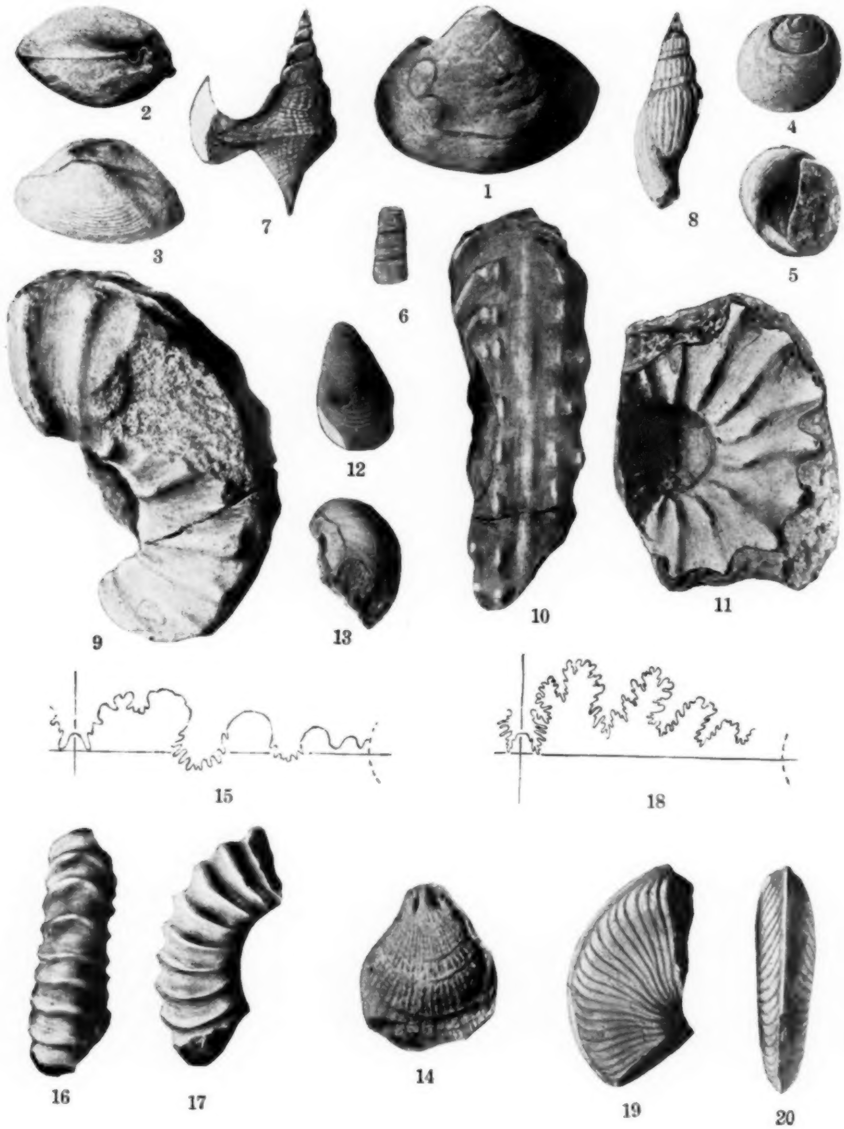
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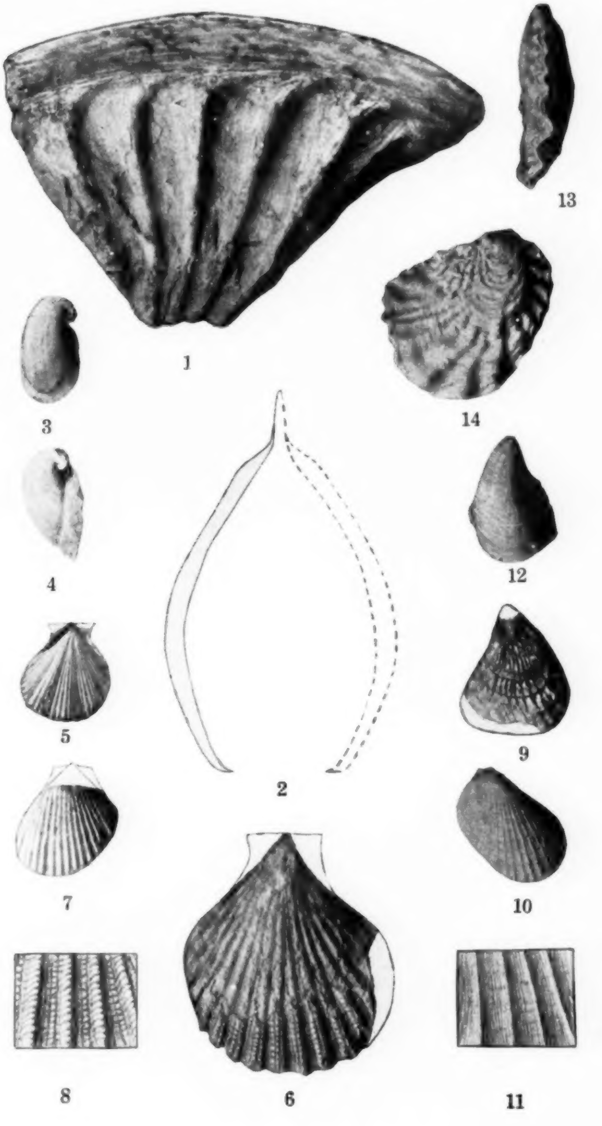
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Figures 10, 11: *Lima* n. sp. aff. *L. intermedia* D'Orbigny. View of only specimen and part of surface (×4) from region between Rio Napo and Cordillera Guacamayos.

Figure 12: *Inoceramus concentricus* Parkinson. Side view of an internal cast from region between Rio Napo and Cordillera Guacamayos.

Figures 13, 14: *Ostrea syphax* Coquand. Side and front views of specimen from region between Rio Napo and Cordillera Guacamayos.

All figures except figures 8 and 11 reduced one-seventh.

CALCIUM CHLORIDE WATERS, CONNATE AND DIAGENETIC[1]

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ABSTRACT

These waters can best be explained as the result of the absorption of water, magnesia, and other compounds in the formation of chlorite and the change of volcanic glass to bentonite. The permutit water-softening reaction may occur as described by Renick and renders the connate Na:Cl ratio more uncertain.

There is little or no sign of the permutit regenerating reaction, or of the petrographic products to be expected.

There is some indication that waters in rocks largely composed of volcanic ash are likely to have calcium chloride, and such rocks are likely to have magnesium in amounts which can be explained as absorbed from the water. It also appears that there is a similarity in undisturbed connate waters of the same geologic age, but the effect of circulation from former land surfaces represented by unconformities is pointed out.

It is perhaps premature to suggest that in some cases the same shower of volcanic ash may have devastated the sea bottom and killed the animals that yielded the oil, or yielded the silica to the oil-making diatoms and furnished the chlorine for the salt water that is found with oil.

INTRODUCTION

In two recent papers Hudson and Taliaferro[2] have called attention to the calcium-chloride waters, a variety of the salt waters that so commonly accompany oil, and have given some facts that may throw light on their origin. The matter being thus brought to my attention, I prepared for the Tulsa meeting of this Association in 1927 a paper explaining the conclusions which I had reached some years ago.[3] I also considered the light thrown on the matter not only by the valuable papers of Hudson and Taliaferro, but by the more widespread recognition of bentonite, and some recent work of M. A. Peacock.

Mr. Hudson was kind enough to write some comments, proper regard to which I hope I have given in this paper.

[1] Read before the Association at the Tulsa meeting, March 26, 1927, by E. E. Fairbanks.

[2] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 1071–88, especially p. 1081, and Vol. 10 (1926), pp. 775–78.

[3] *Proc. Lake Superior Mining Institute*, Vol. 13 (1908), p. 63; *Journal Canadian Mining Institute*, Vol. 12 (1909), p. 127; "Keweenaw Series of Michigan," *Geol. Surv. Michigan Pub. 6* (1911), p. 776 and pp. 844–48; "Mine Water Composition an Index to the Course of Ore-bearing Currents," *Economic Geology*, Vol. 9 (1914), pp. 248–53.

THE ORIGIN OF THE CALCIUM CHLORIDE WATERS

In explaining these waters, characteristic analyses of which are given by Hudson and Taliaferro and myself in the papers cited and also in the table at the end of this paper, there are several factors to be considered:

1. Many such waters possess strength, that is, total solids, much greater than that of sea water, and approaching saturation.

2. Their occurrence is widespread, and in a variety of rocks.

3. The ratio of the bases is peculiar. In contrast with sea water or with bitterns derived from sea water the magnesium is in general very low, while the calcium is very high in proportion to the sodium. No such water could possibly be produced by the evaporation of a present sea water, nor have I supposed that they were so produced, though I have accepted the hypothesis that the composition of the ocean has changed in the course of time. Hudson and Taliaferro are therefore correct in saying that I thought they may have been derived from a primordial sea water that was a weak solution of calcium and other chlorides. I inferred, however, that the water, magnesia, and other constituents were disposed of, not by evaporation, but by absorption in, and hydration of, the containing rock in the course of underground circulation. Such a change in composition in circulation would not produce a "bittern" as I use the term.

I should think that it would be more nearly correct to say that Mills and Wells,[1] who accounted for the concentration by the assumption that the water was evaporated through underground gas, took them to be bitterns.

This theory may work if there is enough of a current of gas into which to evaporate. Otherwise the action would cease as soon as the gas was saturated. It could hardly change the proportions of sodium chloride to calcium chloride without a precipitation of salt much beyond what has been observed. In many places these waters are not associated at all with salt beds. Analyses of bitterns are given by Phalen,[2] and an old but careful and elaborate study of the bitterns of the salt industry of the Saginaw Valley was given by O. C. Hahn[3] which shows clearly how improbable it would be that these waters should be formed by any process analogous to salt manufacture. In all these, as in the few analyses of

[1] *U.S.Geol.Survey Bull.693;* see also discussion in the *Transactions of the A.I.M.E.*, Vol. 65 (1920), pp. 1, 265–67.

[2] *U. S. Geol. Survey Bull. 669*, pp. 240–48.

[3] *Berg und Hüttenmänische Zeitung*, Vol. 26 (1867), pp. 97, 135, 161, 185, 209, 221, 238, 254, 283, 305, 337, 448, especially pp. 161 ff.

natural and artificial bitterns given by Clarke,[1] the tendency to accumulate magnesium is noteworthy.

The absence of magnesium in their waters is remarked by Hudson and Taliaferro and leads them to think these waters are not bitterns. Yet the method these writers suggest for their formation does not explain its absence. Hudson and Taliaferro's conception of a water accumulating in "arid" basins and becoming modified through deposition of carbonates and sulphates, which would enter the accumulating sediments as constituent minerals leaving a "residual" liquor, reminds one of the production of a bittern.

On the other hand the absence is easily accounted for if, as I later suggest, the water and magnesium have gone into the formation of chloritic minerals.

THE CONNATE WATER

It does not really make much difference in my explanation of these waters whether they were originally juvenile volcanic waters or sea water. But I still think we should allow for some change in the sea water in course of time. Every other body of water without outlet becomes salt in time. Rain water and even "salt breezes" have less salts than river water. The average sedimentary rock has less sodium than the rocks from which it was derived, as Van Hise and Bastin have urged.

The absence of salt and gypsum in the oldest rocks and in the Keweenawan at the beginning of the Paleozoic, as compared with series so lithologically similar as the Permian and Triassic at the end, is consistent with less salt in the earlier ocean.

We also find that the early Cambrian species are thin-shelled and phosphatic forms, whose chitinous and phosphatic shells are not so subject to attack by fresh water, and in that respect resemble fresh-water forms of today.

So whether or not one accepts my theory of a "Collozoic" age—that animal life had no hard parts and did not receive the chemical stimulus to vary in the direction of secreting hard parts until the concentration of the ocean had passed the "physiological optimum" (of eight parts per thousand)—to say that the theory of a primordial weak calcium chloride water has "nothing" to commend it is a little strong!

The objection that it is difficult to see how life could have existed in waters of this character may be answered both by saying that it seems as though life did find it difficult to exist in pre-Cambrian times, and by remarking that some life does exist now, even under apparently more

[1] "Data of Geochemistry," *U. S. Geol. Survey Bull. 770*, pp. 170, 172, 220.

strenuous conditions. However, the waters which Hudson and Taliaferro have studied occur in rocks of Tertiary age, in the Sespe formation of Ventura County, California, so that it is a perfectly fair and important objection that no appeal to originally different connate waters can account for them, for these cannot have been very different from sea waters of today.

So then let us see whether my theory, which originally applied to waters which occurred in a series of lava flows with very subordinate sediments, can possibly be stretched so as to cover these Ventura County Sespe waters without assuming that they have worked up from below by some fault, of which there is, so far as I know, no evidence. It is perfectly possible that I may have applied my conclusions too sweepingly.

DIAGENETIC CHANGES

The waters to which my theory was applied were contained in the Keweenaw series, which was mainly a series of lava flows, like those of the Hawaiian Islands. Like those rocks, the tops of the lava flows, and some whole flows, were porous, some were ropy and vesicular like the so-called "pahoepahoe," and some a mass of clinkery fragments, each vesicular in itself. Laid down beneath the atmosphere they may have been filled with volcanic gases. Some meteoric water may have mingled with them, though so long as the lavas were boiling hot it could not penetrate far. In the Hawaiian Islands there are places miles from the coast where the ground-water level is only a little above sea-level, and according to a private letter from H. S. Palmer the estimates of the porosity of the beds, made by several competent geologists, averaged 30 per cent.

Suppose the Hawaiian Islands to be slowly submerged. Little by little the gases would cool, the oxygen and other gases, except perhaps the nitrogen, would be absorbed, and water would take their place. But this water itself would be more or less absorbed in making zeolites and chlorite, which contain more water than volcanic glass.

When the water had been absorbed to such an extent that the residue of salts with a strong affinity for water was great enough, a balance would be reached and water would be no longer absorbed. Calcium chloride has a well-known affinity for water, which makes it useful in laying the dust of roads, and would naturally be prominent in the water so left.

This theory was well substantiated by conditions in the copper country, where, below one or two thousand feet of fresh surface water and an intermediate water extra strong in sodium chloride, as far as mining had

gone, very small quantities of an exceedingly strong calcium chloride water were encountered; where the amygdaloids occur at great depth and near the surface, weighing 2.84 tons per cubic meter, as compared with 2.88 for the compact trap that is not much less porous; and where minerals containing water, such as epidote, chlorite, laumontite, and prehnite also occur in depth. Chlorite, particularly, or possibly serpentine, is omnipresent, and fresh olivine is almost unknown. Chlorite has in fact replaced whole boulders of porphyry in the Calumet conglomerate.

Similar waters occur also in the Lake Superior iron mines. To these I called attention in the paper presented before the Canadian Mining Institute, previously cited. Hotchkiss, M. C. Lake of the Ashland mine, Stephen Royce, George H. Abeel, Jr., and others have also studied them.

Lake was inclined, more than I, to attribute their salt to leaching, and I believe he is right; but I said in 1909, "There is no positive proof that in some cases and to some extent it is not due to volcanic emanations or leached from silico-chlorides and the like." I would now go further and say that there is positive evidence that in some cases and to some extent it is due to volcanic emanations and leached from the silico-chlorides of volcanic glass.

But all these changes, which go on without changing appreciably the volume of the rock as a whole or crushing its constituents, we may class as diagenetic changes. With the changes in the rock there must be corresponding changes in the interstitial water. Let us consider some of them.

THE PERMUTIT REACTION

Hudson and Taliaferro mention two reactions, which have come into commercial prominence of late, which were unknown to me when I wrote the papers previously cited. They are the bases of a widely used water-softening process, and I remember how impressed I was with their geological importance when Professor Sherzer, of Ypsilanti, explained them to me.

These reactions are as follows:

1. A soda zeolite+hard water=a lime zeolite + soft water:

$$Na_2O,\ Al_2O_3,\ (2\text{ to }5)SiO_2\cdot nH_2O+Ca(HCO_3)_2= CaO,\ Al_2O_3(2\text{ to }5)SiO_2\cdot nH_2O+2NaHCO_3\,.$$

This is the reaction which softens hard water, and which Renick[1] and Riffenburg[2] have considered to be responsible for the softening of some

[1] B. Coleman Renick, *U. S. Geol. Survey Water Supply Paper 520-D* (1924), p. 68; see also *Journal of Geology*, Vol. 32 (1924), p. 668 and especially p. 675.

[2] H. B. Riffenburg, *U. S. Geol. Survey Water Supply Paper 560-B*, p. 46.

Montana waters as they work down through Tertiary (Fort Union and Lance) formations for 600 feet more or less (see the analyses cited in the table at the end of paper). It will be noticed that this reaction tends to reduce the amount of calcium in solution, and that a similar reaction may be written for magnesium and iron, and for sulphates as well as carbonates.

A second reaction, that to which Hudson and Taliaferro especially appeal, is depended on to renovate the action when it has run down, and to regenerate the sodium zeolite. To do this a strong solution of sodium chloride is run through the patented zeolite and the reaction is reversed, thus:

2. Run-down permutit+common salt=permutit+calcium chloride:

$$CaO,\ Al_2O_3,\ (2 \text{ to } 5)SiO_2+2NaCl=Na_2O,\ Al_2O_3,\ (2 \text{ to } 5)SiO_2+CaCl_2\,.$$

This reaction permits the accumulation of calcium chloride at the expense of sodium chloride. But, as Hudson and Taliaferro point out, it has a limit, and in weak solutions of sodium chloride the ratio of calcium to sodium does not rise above 1:2, and in stronger solutions not above 1:5, whereas in the waters we are considering the calcium may be more than the sodium.

Again there must remain in the rock a sodium silicate, such as albite or analcite, and we should be able petrographically to follow the change from a calcium aluminum silicate to a sodium aluminum silicate, as discussed later.

Moreover, the permutit reaction does not increase the total solids. Hudson and Taliaferro give for comparison waters of the Dead Sea, Red Lake in the Crimea, and Elton Lake, Russia, which are all more concentrated. I am not able to find any surface waters or shallow waters of the kind demanded (see table of analyses at end of paper). I have recently received, through the kindness of R. A. Smith, the state geologist, analyses of waters from Michigan wells of rather shallow depths and different horizons, in addition to those previously published. Without exception, when the sodium has been determined, its ratio to chlorine is as high as, or higher than, the ratio called for by the figures for the several eras on my Lefax geologic sheet.[1]

Some years ago Wherry pointed out that methylorange gave a calcite test, turning pink with calcite but not with dolomite. I have noticed that some clays have the reverse power, and turn it yellow if slightly pink,

[1] Lefax, Inc., Ninth and Sansom Streets, Philadelphia, Pennsylvania, *Loose-Leaf-System* (2d ed.), Sheets 9–358.

presumably by adsorption of the alkali as described in the references cited by Renick.[1]

If we look over the composition of the river and lake waters of the United States as collected by F. W. Clarke and W. D. Collins,[2] we find it almost universally true that there is no chlorine in excess of what might be combined with the sodium. Great Salt Lake is probably the only exception, and even here, as in Pyramid Lake, Nevada, oölitic granules of calcium carbonate, not sodium zeolites, are being precipitated along the shores.

There seems therefore to be no sign of a tendency to drop sodium and work toward a calcium-chloride water in these surface waters any more than in the underground waters cited by Renick and Riffenburg. Nor do recent studies of the composition of water working through the sulphide-bearing ore bodies of the West show any tendency to accumulate calcium chloride. On the contrary, the carbonates and sulphates of sodium accumulate in the water.

Yet it is an important feature of Hudson and Taliaferro's paper that they have called attention to facts that show exceptions to the rule I used to depend on, that the lowest Na:Cl ratio in a formation was that of the connate water.

Before we leave the permutit reactions, however, there are a few petrographic facts to be cited, some of which favor Hudson and Taliaferro's suggestion. Any reaction tending to increase calcium in the water must tend to increase sodium in the rocks. Now it is true that in many places in the upper parts of the Keweenaw lava flows, which tend to be wetter and more amygdaloid, there is more sodium and the feldspar is nearer albite. I accounted for it as a magmatic effect,[3] but this other interpretation might be considered.

Albitization is a widespread phenomenon, as Daly[4] pointed out. Cleavelandite (albite that is secondary) is found in pegmatites, and we are finding analcite not too uncommon, as well as natrolite. For example M. A. Peacock mentions the presence of analcite in altered basaltic glasses.[5] The more the presence of these was coincident with the calcium-

[1] Renick, *op. cit.*, pp. 63–66; see also Collins, in *Industrial and Engineering Chemistry*, Vol. 15, No. 4 (1924), p. 394.

[2] F. W. Clarke, *U. S. Geol. Survey Prof. Paper 135* and *Bull. 770;* W. D. Collins, *U. S. Geol. Survey Water Supply Papers 496* and *559*.

[3] *Michigan Geological Survey*, Vol. 6, Part 1, pp. 146–47.

[4] R. A. Daly, "Low Temperature Formation of Alkaline Feldspars in Limestones," *Proc. National Acad. Sci.*, Vol. 3 (1917), pp. 659–65.

[5] *Trans. Roy. Soc. Edinburgh*, Vol. 55, Part 1, No. 3 (1926), p. 63.

chloride waters, the more would the second permutit reaction, that of regeneration, be indicated.

But in the Keweenaw mines the analcite seems to be more common in the upper levels, where the water contains more sodium. It is less common in the greater depths where the calcium-chloride waters occur, and the lime zeolites are more common.

Again, the spilitic pillow lavas run high in sodium and are subject to albitization. This has been attributed to their being submarine effusions, and in that case their chemical character would fit in with the second permutit (calcium-chloride generating) reaction.[1]

On the other hand, the sedimentary rocks are as a whole lower in sodium than the igneous rocks from which they were presumably derived.

THE ELIMINATION OF SULPHATE

It is hardly necessary to dwell on the low sulphates of the Sespe waters, commented on by Hudson and Taliaferro, a common feature of the calcium-chloride waters, since the explanation advanced by myself[2] and by others has been strengthened by G. S. Rogers,[3] and put beyond question by the recent work of E. S. Bastin.[4]

I do wish, however, to remark that the reactions given by Bastin, as representing the views of those who treat the reaction without regard to the coöperation of organisms, show no absorption of water, but the contrary. For instance:

$$CaSO_4+CH_4=CaS+CO_2+2H_2O\ .$$

Moreover CaS tends to decompose in the presence of water in a reversible reaction into H_2S and CaO_2H_2, and I have found that H_2S waters are not uncommonly alkaline when the H_2S has left them.

If underground the H_2S is removed by diffusion into a circulating current of gas or oil (where it is commonly found), the calcium hydrate might react with the CO_2 and be precipitated as carbonate or behave as does the calcium hydrate added to the Saginaw brines: throw out the magnesium and iron first.

[1] H. Dewey and J. S. Flett, *Geological Magazine*, Vol. 8 (May and June, 1911), pp. 202–9 and 241–48 with bibliography.

[2] *Michigan Geological Survey*, Vol. 7, Part 2, Huron County (1900), pp. 141, 152.

[3] *U. S. Geol. Survey Bull. 653* (1917), p. 94; also see analyses in table at end of this paper.

[4] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (December, 1926), pp. 1270–99, with references to previous work; also *Journal of Geol.*, Vol. 34 (November-December, 1926), pp. 783–90.

I mentioned a crust of pyrite-cemented rock just above water or oil at Sebewaing formed through some such reaction as this cited by Bastin,

$$Fe_2O_3+3H_2S=2FeS+S+3H_2O\ .$$

But as I have not heard much or seen much of pyrrhotite that seemed to have been formed in this wet way, but rather FeS_2, although I have seen sulphur clearly produced from the decomposition of H_2S, I am inclined to think that some such analytical equation as the following, if we neglect the bacteria, is more representative of what goes on:

$$2CaSO_4+(2CH \text{ or } CH_6)+H_2Fe(CO_3)_2=2CaCO_3+(H_2O+2CO_2)$$
$$\text{or } (3H_2O+CO_2)+FeS_2$$

gypsum+organisms+bicarbonate of iron=calcite+carbonic acid+ pyrite.

We see that the reduction of the sulphate tends to produce CO_2 and water and to decrease the concentration.

Bastin does not pretend to give any chemical reaction to show just the use the bacteria make of the sulphur, and part of the sulphur may well remain dissolved in the petroleum in some organic compound. Yet I do not think bacterial action can change the conclusion that, while the removal of sulphates is easily accounted for, the tendency is to form water rather than remove it, and the increase in concentration requires another explanation.

CHANGES IN CARBONATE

In ocean water the carbonate radical is kept very low by organisms that carry it down in their skeletons and shells, but the diagenetic reduction of sulphates tends to increase carbonates, and none of the sets of analyses cited by Hudson and Taliaferro, Rogers, Renick, or Ambrose[1] shows any systematic decrease in carbonate with depth. In fact the deepest Sespe holes have more carbonate than the average. On the other hand, some of the Michigan calcium-chloride waters have extremely low carbonate, though there is calcite crystallized from solution, commonly in large clear crystals. Heat and a chance to attack a silicate might precipitate the carbonate, and as the carbonate is much less soluble than the bicarbonate, an alkaline hydrate formed from the sulphate as previously described might tend to precipitate the carbonate. Magnesia would come down before lime, and thus might be promoted the dolomitization which occurs in the Trenton limestone when it becomes an "oil sand."

[1] A. W. Ambrose, *U. S. Bureau of Mines Bulletin 195*, and *Trans. A. I. M. E.*, Vol. 65 (1921), p. 255, and others previously cited; see also analyses at end.

ELIMINATION OF MAGNESIUM

As already mentioned, the striking thing to be explained in these waters is the elimination of magnesium which is characteristic of the Sespe waters as well as those of the copper mines, and is widespread. The magnesium is low as compared with sea water or river water, whereas in bitterns it is relatively high. According to Daly,[1] magnesium was precipitated from the ocean more promptly in pre-Devonian time than at present. Most of the waters we are discussing are, however, post-Devonian.

That magnesian waters in the presence of limestones tend to produce dolomites, as illustrated at Funafuti,[2] and that various organisms secrete magnesium as well as calcium, especially in warm water, as shown by Clarke, are factors; but they are not sufficient.

In permutit reaction No. 1, magnesium will be eliminated, and Renick's[3] analyses show a great lowering of the magnesium, but only with the calcium.

If we could imagine the calcium and magnesium precipitated out as nearly as has happened in Renick's deeper waters and then have only calcium added, we might then account for the absence of magnesium and the high content of calcium. The first step is reasonable, but we then have to provide for a very large replacement of sodium by calcium. In spite of the diagenetic production of albite, the references to which Daly has collected,[4] I do not think this can be expected, certainly not without circulation of the water and reaction with the rock. Moreover, this does not account for increased concentration of water.

The Sespe waters are, however, not so concentrated as some of those I studied. It might be worth while to study the rocks from which the Sespe waters came to see if there were any low-temperature albite.

On the other hand, the increase in concentration (and on the whole the Sespe waters of the calcium-chloride type are concentrated, as compared with other California waters) and the decrease in magnesium are both accounted for by supposing that they are used in building a chloritic mineral. For the purpose of this paper I shall include as chlorite all the hydrous magnesian, more or less aluminous, minerals.

[1] *Bull. Geol. Soc. Amer.*, Vol. 20 (1909), pp. 164–66.

[2] F. W. Clarke, *U. S. Geol. Survey Bull. 770*, pp. 575 and 579; Steidtman, *Bull. Geol. Soc. of Amer.*, Vol. 28 (1917), p. 438; Sollas, *Age of the Earth*, article on "Coral," *Encyclopedia Britannica* (11th ed.), Vol. 7, p. 134.

[3] *Journal of Geology* (1924), p. 675; see end of this paper.

[4] R. A. Daly, "Low-Temperature Formation of Alkaline Feldspars in Limestone," *Proc. Nat. Acad. Sci.*, Vol. 3 (1917), pp. 659–65.

This will include not merely the chlorites of the traps of the Keweenaw series,[1] but the white chlorites, such as sheridanite and colerainite, upon which Conner, Larsen, Shannon, and Wherry[2] have worked. It includes also the "bentonite" minerals which run off into pure aluminous minerals, such as montmorillonite, leverrierite, beidellite, halloysite, and other clay minerals.[3] Glauconite and greenalite are also names applied to minerals that may carry some magnesium as well as water,[4] are diagenetically formed, and exchange bases readily, like permutit.

The formation of chlorite is one of the commonest secondary actions. I had suggested it as an explanation for the copper-mine waters, and Rogers had suggested the possibility that the magnesium was precipitated as a silicate, "though no evidence was obtained in the field."[5] Compare, however, the analyses of bentonite, of which types are given in Table I, with the rhyolites from which they are altered.

Analyses from Daly and from Fenner are put beside them in the table for comparison. It is clear that if we take the alumina as a standard of comparison the rhyolite has lost in almost everything but magnesia and water. It is much more natural to assume it has gained in both of these. I do not think that anyone would doubt that it had gained in water. While we do not know that a particular bentonite came from a particular rhyolite, we can be reasonably certain that none of the igneous rocks high in silica, such as make pumice and volcanic ash, have enough magnesia in proportion to the alumina to make bentonite. Either the alumina has been leached more than the magnesia (which is contrary to all general beliefs and observations) or magnesia has been added.

Other illustrations in Table I come from a series of papers recently published by M. A. Peacock on the volcanic rocks of Iceland. He was not studying rhyolites so much as basaltic glasses, but in these the change from fresh basaltic glass or "sideromelan" to altered "palagonite" is accompanied by a great development of chlorite, which he elaborately describes, as well as of zeolites. Besides the enormous increase of water to something like a quarter of the rock, and decrease in alkalies and lime, we find the magnesia at least holding its own. F. G. Thwaites has sug-

[1] A. C. Lane, *Pub. 6, Michigan Geological Survey* (1911), and previous reports.

[2] E. T. Wherry, *Jour. Mineralogical. Soc. of Amer.*, Vol. 10 (1925), p. 65; *Jour. Wash. Acad. Sci.*, Vol. 12 (1922), p. 239.

[3] C. S. Ross and E. T. Shannon, *Jour. Amer. Chem. Soc.*, Vol. 9 (February, 1926), pp. 79–87.

[4] C. S. Ross, *Proc. U.S. Nat. Museum*, Vol. 69 (1926), pp. 1–15.

[5] G. Sherburne Rogers, *U. S. Geol. Survey Bull. 653* (1917), p. 43.

gested to me that the fact that there is more calcite in veins than magnesium carbonates may also help to account for the accumulation of magnesium under some conditions.

TABLE I

DIAGENETIC CHANGES IN VOLCANIC GLASSES

	Rhyolite		No. $2\times\frac{22.93}{13.77}$	Bentonite			Sideromelan	Palagonite	Bardolite
	1	2	3	4	5	6	7	8	9
SiO_2	74.74	72.62	121.2	49.56	54.62	40.40	46.39	35.34	38.36
TiO_2	.28	.25	.42	0.40	0.37	0.44			
Al_2O_3	13.01	13.77	22.93	15.08	29.67	28.80	16.27	11.15	5.54
Fe_2O_3	.82	1.29	2.15	3.44	1.14	.74	1.35	10.28	16.59
FeO	1.43	.90	1.5	.45	0.21		9.96	2.19	4.60
MnO	.05	.12	:2	.01		.0	tr.	0.22	
MgO	.70	.38	.63	3.10	2.26	3.80	9.77	6.52	9.41
CaO	2.12	1.43	2.38	1.08	1.46	.74	13.00	7.01	0.73
Na_2O	4.32	3.55	5.82	7.84	2.23	1.68	1.40	0.16	0.46
K_2O	2.60	4.09	6.8		2.77	4.98	0.15	0.19	4.67
S±					4.53	3.02	0.15	8.90	
H_2O	.20	1.53	2.55	22.96	3.03	6.13	0.10	15.50	19.50
P_2O_5	.09	.01	.12		.54	.13	.05	.24	

1. Katmai (Novarupta) obsidian, after C. N. Fenner, "The Katmai Magmatic Province," *Jour. of Geol.*, Vol. 34, No. 7 (October-November, 1926), pp. 675–772; see also *Jour. of Geol.*, Vol. 28 (1920), p. 583.

2. Average rhyolite, Daly, *Proc. Amer. Acad. Arts and Sci.*, Vol. 45 (1910), pp. 211–40, especially p. 218; also *Igneous Rocks and Their Origin*, p. 19, No. 7.

3. No. 2 increased so that the alumina is the same as in the bentonite (No. 4), which is supposed to be from a similar rock.

4. Otaylite, a bentonite, near Otay, California, Ross and Shannon, *Jour. Amer. Ceramic Soc.*, Vol. 9 (1926), p. 88.

5. Bentonite, private communication of Wilbur A. Nelson, but similar analyses are given in his printed reports. CO_2.0.12. G. H. Nichols, analyst.

6. Bentonite from Pennsylvania. T. W. Mason for C. A. Bonine, *National Research Council, Researches on Sedimentation.*

7. Sideromelan, M. A. Peacock, *Trans. Royal Soc. Edinburgh*, Vol. 55, Pt. 1, No. 3, p. 57.

8. Palagonite, M. A. Peacock, *Trans. Royal Soc. Edinburgh*, Vol. 55, Pt. 1, No. 3 (1926), p. 66.

9. Bardolite, Moroszewicz, *Bull. de la Soc. Française*, Vol. 47 (1924), p. 52.

ELIMINATION OF WATER

The elimination of water was easily accounted for in my early studies in the Keweenaw rocks, for some chlorite was all through the traps, and in addition minerals like epidote and laumontite (a lime zeolite which seems to suffer no permutit effect from the water).

But I did not then see how to account for this in the wide range of rocks in which the calcium-chloride waters occur, such as the Sespe formation. I now see that an explanation may lie in the hydration of volcanic ash and glass like the bentonite which are generally overlooked. If we stop to think of it, some volcanic ash must commonly occur and be very widespread, though so little recognized, even as the bentonite ash of the Ordovician was for years unrecognized. Yet it is reported now from Kentucky, Tennessee, Virginia, Minnesota,[1] and Pennsylvania. It must have covered the whole Mississippi Valley and have been penetrated in hundreds of drill holes and not been recognized by myself and others.

For this hypothesis there are two lines of evidence: (1) the bentonite shows precisely the kind of absorption of water and magnesia that would account for these waters, and (2) some wells in which a large amount of volcanic material was encountered contain the strongest calcium-chloride water.

Let us consider the first point, the capacity of the chlorites to absorb water.

Moroszewicz finds that his bardolite,[2] lying between chlorite and biotite, the analysis of which is given in Table I, No. 9, gradually loses as much as 19.17–29.56 per cent of water as the temperature rises. Three-quarters of this, more or less, according to the humidity of the air, will be reabsorbed on cooling.

Ross and Shannon also found their bentonite (Table I, No. 4) very hygroscopic, and give it a formula $(H_2MgCa)\,O \cdot Al_2O_3 \cdot 5SiO_2(5 \text{ to } 7)H_2O$, and Ross also recognizes magnesium and water as essential constituents in glauconite. Glauconitic sandstones are very widely referred to, but probably often without such tests as would surely distinguish them from quite magnesian chloritic minerals.

The papers of Peacock, already cited, show not only that the basaltic glass known as sideromelan rapidly and easily changes to palagonite and goes even farther in changing to chlorite and some zeolite, retaining magnesia but with a very large absorption of water, but also that there is a trace of phosphorus in the glass, so that when the rock crystallizes out completely we are very likely to find needles of apatite such as occur at the Capo de Bova in Rome and in the acid interstices which I have described in my Isle Royal report. But in apatite there is a little calcium chloride. Thus the decomposition of such a glass will at the same time furnish an absorption of water and some amount of calcium chloride. We

[1] *Pan-American Geologist*, Vol. 46 (August, 1926), pp. 11–15.

[2] *Bull. de la Soc. Française*, Vol. 47 (1924), p. 46.

seem, therefore, to have a source of the chlorine of the ocean waters either in direct volcanic fumes or in the leaching of the glass which may fall into the ocean.

Now as to the second line of evidence, that is, the occurrence of these waters where there is much volcanic glass in the country rock: I have given reason to believe that the Keweenawan formation was a great series of lavas, like Kilauea or Mauna Loa, largely filled with gas, as they now are, which slowly sank and were buried below water level, and slowly absorbed water. The waters soaking in might at the same time lose both sodium and water.[1] Moreover, in a more recent visit to the Calumet and Hecla mine, where I had a chance again to study the boulders whose change to chlorite and also to copper I had already described,[2] I was impressed with the fact that not all boulders suffered this extreme alteration. The boulders were not amygdaloids, for there were many of these not so altered. Nor were they the porphyries, which occur so plentifully in this conglomerate. I was convinced that they were originally different, and probably a vitrophyric porphyry, somewhat like an andesite in composition. In that case the *type of alteration is precisely like that of the bentonite and palagonite, and magnesia and water are absorbed from outside in the decomposition of the glass.*

In a very recent number of this *Bulletin*[3] Hudson and Taliaferro have given grounds for the belief that we may find, in the reaction with volcanic ash, a clue to the origin of the Sespe formation, Ventura County, waters they studied. They give a record of a well encountering a great thickness of igneous rocks and tuff. They do not, however, think this is characteristic of the calcium-chloride wells, yet volcanic activity is widely reported in the California Tertiary, suggesting that there is very probably volcanic ash in the wells that yield calcium chloride. Still, no correlation of ash and chlorides has yet been found. There is room for investigation.

SOLUTION OF CHLORINE

The widespread occurrence of chlorine in igneous magmas, in apatite, in the salt water of quartz inclusions, and in glass, as shown in the Novarupta glass analysis previously given (Table I, No. 1), is well enough known now.

Besides the accessible work of Day and his colleagues of the Geo-

[1] Renick, *Journal of Geology*, Vol. 32 (1924), pp. 668, 684.

[2] *Economic Geology*, Vol. 4 (1909), pp. 158–73.

[3] Vol. 10 (August, 1926), pp. 775–76.

physical Laboratory at Washington, we may cite that of Brun,[1] who has for the last quarter of a century devoted himself to the study of volcanic action and emanations and shown the importance of calcium chloride, both in the crystallization of igneous rocks and as a mineralizer. We take from his paper of July, 1909, p. 55 (p. 11 of reprint) certain analyses which show the chlorine present in volcanic glass, as well as the volume of gas and the temperature at which the obsidians exploded and gave off the gas. His work has been controverted by Gautier, Day, and others, and he may have overestimated the rôle of chlorine and underestimated that of water, but I think he has shown clearly enough for the purposes of this paper that the decomposition of volcanic glass may add chlorine and absorb water. He has had wide experience and has made many valuable observations.

Other analyses of volcanic gases are assembled and referred to by Clarke,[2] including an account of the very important work of Day and his colleagues, who found no chlorine and much hydrogen in Kilauea gases. This may be connected with the fact that the rocks at Kilauea are basic lavas, and not obsidians, such as the rocks cited in Table II.

F. G. Clapp,[3] in studying the waters of Maine, found several waters high in chlorides in the granites, which he took to be magmatic. In one which may be such, at Vinalhaven, the Na:Cl ratio was down to 465:790

[1] A. Brun's publications are mainly in the *Archives des Sciences physiques et naturelles*, Geneva. Volume 13 (April, 1902), p. 367, contained a study of the fusion points of minerals. This was continued with English and German abstracts in the reprint of December, 1904. A series entitled "Quelques recherches sur le volcanisme" was published as follows: chapters 1 and 2 in Vol. 19 (May 15, 1905), pp. 438–50; chapters 3–6, completing Part I, June 15, pp. 589–703; Part II in Vol. 22 (November, 1906), p. 425; Part III in Vol. 26 (1908), p. 146; Part IV in Vol. 27 (February, 1909), p. 113; Part V in Vol. 28 (July, 1909), p. 45; and a note on "Exhalaison volcanique secondaire" appeared in Vol. 29 (December, 1909). These were collected and issued in a well-illustrated quarto volume, *Recherches sur l'exhalaison volcanique*, published by Kündig (Geneva, 1911). They were summarized in the *Revue générale des Sciences* (January 30, 1910), pp. 51–58. In *Eclogae Geologicae Helveticae* (*Proc. Swiss Geol. Soc.*), Vol. 12, No. 2 (November, 1912), p. 172, he has a valuable discussion on the low temperatures at which granitic and alkaline aluminous magmas crystallize owing to the presence of chlorine, and in the *Bulletin of the French Mineralogical Society*, Vol. 36 (February–March, 1913), he discusses the rôle of the water in micas which he considers analogous to that of the zeolites, as it can be lost without changing their crystalline network. In the *Archives*, Vol. 44 (1917), p. 5, he replies to Day, who challenges his conception of volcanic action as anhydrous.

[2] "Data of Geochemistry" as previously cited, chap. viii.

[3] *U. S. Geol. Survey Water Supply Paper 223*, p. 77.

=0.26, and others were lower. In granites one could hardly expect permutit reaction to lower the sodium.

Even more striking are analyses[1] that come from a diamond drill hole deep in the granite under Hudson River, put down in connection with the great New York aqueduct. It will be noticed that the Na:Cl ratio will come out about 0.22.

TABLE II

GASES IN VOLCANIC GLASSES

	E	F	G	H	I
Cc. gas per kg. at 9° C. and 760 mm...	417	371	370	754	165
Exploding temperature ° C.........	991	....	....	870	....
Composition in percentage of volume:					
Cl_2 with a little S_2Cl_2............	14.47	18.29	18.34	tr.	13.45
HCl gas........................	50.75	45.82	50.10	89.22	6.06
SO...........................	8.31	13.45	0.89	7.72	65.83
CO_2...........................	9.83	absent	15.46		tr.
O_2..........................	1.43	"	tr.	tr.	tr.
N and CO......................	15.21	22.44	15.21	3.06	14.66
	100.00	100.00	100.00	100.00	100.00

E. Road metal from the River Manoek near Garoet, Java (Tji Manoek).

F. From the volcano Patoeha, 30 kilometers south of Bandoeng, Java, Longitude 107°41′ E.

G. From a great obsidian flow descending from Kendang, near the village of Pasir Kiamis, west of Garoet (Java), Longitude 107°53′ E.

H. From a Lipari flow, covered with pumice, Longitude 15° E.

I. From Montana Blanca (White mountain) Pico de Teyde, Canary Islands, Teneriffe, 16°39′ W.

Also in E and F there were 12 and 32 mg., respectively, of solid NH_4Cl condensed in the apparatus; in G it was not determined; in H there was a strong ferriferous sublimate; and in I it varied in some varieties. A, B, C, D, not here given, were all from Krakatoa and essentially similar.

The Lytton Springs oil field of Caldwell County, Texas,[2] shows waters which yield 14,500 parts per million that are close to a *serpentine which may well have absorbed water and magnesium in hydrating* and given off chlorine, although in the lower water the Edwards formation has but 5,000–6,000. However, the author's suggestion of explanation of a deeper-seated water working up a fault is, of course, by no means to be ruled out.

[1] These analyses I owe to the wide interest and enduring and characteristic helpfulness of J. F. Kemp, whom we shall all so much miss.

[2] D. M. Collingwood and R. E. Rettger, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (1926), pp. 964–76.

A more striking illustration of apparent connection with igneous rocks is that given by Ickes[1] in his account of exploration for oil in Great Britain. He gives a group of analyses of waters, all from deep wells in the Carboniferous. Two of them have a Na:Cl ratio of 0.41, which is what might be expected from my Lefax[2] figures. Others have a higher ratio and are weaker. This points to admixture of circulating water.

But there is one exception, the Apedale well (Table IV, Analysis 14), where the specific gravity is 1.1775 and the Na:Cl ratio is 0.37 at 3,570

TABLE III

ANALYSES OF GRANITE UNDER HUDSON RIVER*

	PARTS PER MILLION	
	No. 1646†	No. 1414‡
NaCl	6,607	5,231
KCl	294	
$MgCl_2$	277	380
$MgSO_4$	248	315
$CaCl_2$	2,013	2,633
CaSO	354	316
$(FeAl)Cl_3$	15	
SiO	tr	8
Fe_2O_3 and Al_2O_3	....	7
Organic and volatile	....	926

* Analyses by R. H. James, chemist to Board of Water Supply, New York City.

† Lab. No. 1646, Storm King crossing. Diamond drill hole 1/A74 East test shaft. Depth 1,018 ft. in granite. Sample by William B. Hoke, Assistant Engineer, September 11, 1909.

‡ Lab. No. 1414, same hole. August 27, 1909. Sample by Galvin Naliman. Depth not given, but probably less than previous one. Total solids, 9,816 per million.

feet depth. Of this hole Ickes writes: "A surprising and unlooked for development was the great thickness of volcanic ash encountered. This was entered at 1,450 feet and continued to the bottom at 4,248 feet, but was a very easy formation to drill. This is by far the thickest volcanic material known in the Carboniferous of England."[3]

We may notice, too, that this well was exceptionally low in magnesium, having only 0.12 grams per kilo as against 35.97 of calcium, while the next strongest, the Renishaw well with specific gravity of 1.127, had Mg:Ca=2.3:15.20.

[1] *Trans. A. I. M. E.*, Vol. 70, pp. 1070–75; also *Mining and Metallurgy*, October, 1923.

[2] Lefax, *op. cit.*

[3] E. I. Ickes, "Recent Exploration for Petroleum in the United Kingdom," *Trans. A. I. M. E.*, Vol. 70, p. 1067.

GEOLOGICAL SIGNIFICANCE OF THE WATER COMPOSITION

In my Lefax[1] geological column I have given certain ratios of Na:Cl as characteristic of certain geological ages. In view of all that has been said of the probability of the addition of chlorine from the decomposition of volcanic glass, do such figures have any value at all?

It is not needful to rehearse the accessible work of Day and his colleagues of the Geophysical Laboratory and of Jaggar in Hawaii, the studies of Fenner, Griggs, and others in Katmai under the auspices of the *National Geographic Magazine*. Granting the possible supply of chlorine from other sources than the ocean and the possibility of calcium chloride from volcanic glasses, and of permutit reactions, what likelihood is there that a Na:Cl ratio is connate—that of the original ocean?

Heretofore, as brought out in my article in *Economic Geology* on "Mine Water Composition as a Guide to Ore-bearing Currents" (already cited), I have picked out those waters which seemed geologically least likely to have had circulation, and then taken the lowest Na:Cl ratio found among them. I no longer can depend on that method with so much confidence, and instead must ask: Among the waters of a certain formation which do not seem likely to have been much disturbed, is there a characteristic Na:Cl ratio for deviations from which there is an explanation, which may therefore be taken as the Na:Cl ratio of the ocean of the time?

I first propounded the question and answered "Yes" at the Ottawa meeting of the Geological Society of America,[2] and gave certain ratios which seemed to me characteristic of the ocean at various dates in the past. Since then F. Reeves, in a thesis for Johns Hopkins University,[3] studied the problem with reference to the Pennsylvanian salt waters encountered in deep wells and reached the following conclusions: The waters at 1,300 feet are by no means intermediate between the surface water and those deeper. (This I found was also true in the Michigan copper mines.) The distribution of the waters suggests that they are not of meteoric origin. There is no adequate explanation of the removal of water of deposition, and dry sands and red beds are associated. He finds the waters three to five times as strong as present sea water, and the ratio of Na:Cl varies with the age of the strata (see analyses in Table IV).

[1] *Op. cit.*

[2] *Bull. Geol. Soc. Amer.*, Vol. 17 (1907), p. 161; *Jour. of Geol.*, Vol. 14 (1906), pp. 221–25; see also *Science*, Vol. 26 (1907), pp. 129–43.

[3] "Origin of the Natural Brines of the Oil Fields," Johns Hopkins University (1917), *Contributions to Geology*, pp. 57–68.

For six Pennsylvanian brines the average ratio is 0.53, but 0.44 for the deepest well (1,800 feet). For eight brines from the Mississippian the average is 0.44, and about the same for the deepest well (2,092 feet). But there is one 1,782-foot well where the ratio drops to 0.34. For five Catskill, that is, upper Devonian, brines the ratio is 0.455; but the lowest ratio, 0.41, is for a 3,094-foot well, which is also very low in magnesium. For four brines from the lower Devonian the ratio is 0.355, with a ratio of 0.40 in the deepest well (6,260 feet). One 2,667-foot well has a ratio as low as 0.29.

Thanks to a private communication from Charles R. Fettke, I can extend the series a step farther by a new analysis of a water from the "Oriskany," at 4,000 to 5,000 feet depth where Na:Cl=0.28 as follows:

Na	56.18=20.79	Cl	208.08=49.93
Mg	7.81= 5.46	SO_4	0.17= 0.03
Ca	56. =23.78		49.96
	50.03		

Fe 0.14, Al 0.06. Total solids 326.89 grams per liter.

As we are approaching the Silurian formation, famous for salt beds, we might conceivably think of contamination from the bitterns of that formation, but the magnesium is very low and we should have to fall back on its diagenetic absorption in making chlorine or in some such action.

If now we make comparison with the waters (Table IV) classed by Rogers as Tertiary connate,[1] we find the average ratio of Na:Cl in the ten analyses from the Midway and Coalinga fields to be 0.56 as against 0.55 in the present ocean. In some of them there seems to be a little sodium from upper waters. This, as his tables 10 and 11 show, makes the sodium percentage at once increase much more than the present ocean ratio. Four analyses from the Sunset field range less, and in three of them the ratio is 0.54.

In only one analysis, as Rogers remarks, is the secondary salinity as high as in ocean water (his No. 48), in which magnesium is lowest as well as calcium highest. It is therefore the one in which I should suspect the most volcanic water or reaction with volcanic ash. Na:Cl=0.50.

Nowhere is the Na:Cl ratio as low as in the waters studied by Reeves. So far as these analyses go, it seems that there is a change in the ocean Na:Cl ratio and that it increases in the more recent rocks, though subject to provoking diagenetic changes.

[1] G. Sherburne Rogers, "Oil-field Waters in the San Joaquin Valley, California," *U. S. Geol. Survey Bulletin 653*, Tables 8–14.

Another way of attacking the problem is to see how nearly constant the Na:Cl ratio is in waters from widely separated regions, but likely to be connate and of the same period. Here I think it cannot be accidental that in the Carboniferous of Scotland as reported by Ickes, of Pennsylvania as reported by Reeves, and of Michigan, Oklahoma, and Ohio as reported by Phalen,[1] waters commonly occur with Na:Cl ratios down to 0.41, but rarely lower. The most simple explanation is that this was the ratio in the ocean water toward the end of Paleozoic time, and that while the decomposition of volcanic glass to produce bentonite, or some chloritic mineral, has absorbed the water and magnesium, there has not been enough chlorine dissolved to disguise the original ratio, and the permutit reactions have tended, except in a few cases, to raise it rather than lower it. However, there is a wide range in the Marshall (Carboniferous) limes.

Comparing these analyses with the many available analyses from the next lower horizon, namely, the sandstones, that used to be called "Potsdam," on the line between the Ordovician and Cambrian, we see that much of the water is meteoric even below 2,000 feet, as at Aurora, Illinois.[2] It may have been working its way down recently, or more probably soon after the formation of the sandstones, which seem to lie close to disconformities, when the sandstones were at or near a land surface.

Roy O. Neal,[3] in his important work on the "Petroleum Hydrology of the Mid-Continent Field," thought that his bottom connate waters were practically connate and equivalent to the present ocean, and Rogers in the discussion that followed called attention to the fact that the results did not sustain my hypothesis of the variation of the composition of the ocean in geologic time. Quite right, they do not. But it must be kept in mind that these bottom waters are fresher than those above, in which one has a Na:Cl ratio of 0.47, while all have less than has the present ocean. Both top and bottom waters have magnesium, but the top waters are three times as concentrated as the bottom waters, and practically devoid of sulphates. I should apply the same explanation which Mills applied in discussion, that in the bottom waters is more meteoric water, which increases the sodium exactly as Ambrose found in the Coalinga waters. To be sure, it may be said, as pointed out by Neal, that it is a remarkable coincidence if a mixture of Paleozoic sea water with meteoric water and subsequent alterations should give so nearly the composition

[1] *U. S. Geol. Survey Bull. 669*, pp. 240–48.

[2] A. C. Lane, *Economic Geology* (1914), pp. 246–47. See also *Bulletin 10* of the *Illinois Geol. Survey*, and *Illinois Water Survey, Bulletin 21*. I have also private communications from F. G. Thwaites.

[3] *Trans. A. I. M. E.*, Vol. 61 (1920), pp. 565–80.

of the present water. But is it any more difficult to believe than that an original water should have remained practically unchanged from Paleozoic time, with a water three times as strong a few hundred feet above it being even now buried only 2,500 feet, especially in view of the fact brought out by Mills in the discussion, that there are probably two periods of uplift and erosion during the Paleozoic? I believe that if we had enough water samples and analyses, such unconformities as bring the Woodbine and Trinity Cretaceous sands together in the region of the Louisiana Sabine uplift, or that bring the Ordovician and Pennsylvanian together in Oklahoma, would be indicated by them. But there is no doubt that buried unconformities and the water associated with them and the possibilities of reaction with volcanic glass complicate the problem enormously.

Still, unless there has been an accumulation of sodium chloride it is hard to explain how we get such low ratios of Na : Cl as 0.08, and even less, in the Michigan copper mines and do not in later rocks. Although the Keweenawan was a land formation, Brun has shown, in papers previously cited, how dry the gases and rocks from a volcanic cone may be for a long time afterward, so that there is no difficulty in assuming a later inhibition of sea water, just as there would be were the Hawaiian Islands to sink beneath the waves.

BEARING ON PETROLEUM ACCUMULATION

It is natural to suggest, inasmuch as salt water is so commonly associated with oil, that if these calcium-chloride waters are in any part derived from volcanic glass, the same ash that yields the chloride also killed the animals or diatoms whose decomposition yields the oil. The diatoms may have got their silica from it! Sardeson[1] has emphasized the destruction and faunal changes produced by such an ash fall.

But there are many other factors that may connect them. For instance, in 1909 and earlier Brun[2] emphasized the presence of hydrocarbons in volcanic ash and the possibility of making oil from NH_4Cl and CaC_2. The saltness of the water may have prevented the decay until the organic matter was safely buried, so that the products of decomposition could not escape. The saltness of the water must also affect the activity of bacteria, the rôle of which in the production of oil and reduction of sulphates Bastin is studying.[3]

[1] F. W. Sardeson, "Pioneer Repopulation of Devastated Sea Bottoms," *Pan-American Geol.*, Vol. 46 (November, 1926), pp. 273–88; also "Beloit Formation and Bentonite" (August, 1926), p. 22.

[2] *Op. cit.*

[3] *Jour. Geol.*, Vol. 34 (1926), pp. 773–92, and *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, pp. 1270–99.

Thus, while it seems to me wise to keep a closer eye out for volcanic ash, it must be remembered that there are other more important factors. The water of sandstones, in which oil is generally found, is, as Mills pointed out,[1] not generally as salt as that of associated limestones. It is only exceptionally that one gets anything like a pure connate water in sandstones. This condition is not peculiar to the Berea sandstone, but it is shown in discussing the Dakota sandstone and Cretaceous oils as well. I would attribute the fresher character to the meteoric water absorbed from a land surface making an unconformity.

The circulation which has driven ahead and accumulated the oil and gas may have also driven ahead the salt water with it, but under it in streaks. No one of these factors can be assumed beforehand to be the most important.

TABLES OF WATER ANALYSES

It has seemed to me best to group together for easier comparison all the analyses that I wished to quote from the several papers cited. They

TABLE IV
WATER ANALYSES

Analysis	Total Grams per Ton	Ca	Mg	Na	Na:Cl	Cl	SO_4	CO_3 or HCO_3
1	477	12	6.1	155	5.2	3	66	381
2	1,580	4.8	3.4	640	2.7	236	6.6	1,332
3	2,102	6	4.2	750	16	48	979	669
4	1,268	4	1.9	516	2.4	118	0.8	9.6+1,169
5	....	1	2	47	23	2	39	9
6	....	2	0	48	4.8	10	28	12
7	....	2	2	46	7.7	6	8	24
8	....	1	0	49	9.8	5	1	29
9	....	1	1	48	2.8	17	2	31
10	1,641	45	26	457	5.2	88	814	143
11	2,276	62	28	799	1.7	480	22	784
12	34,755.2	2,894	7	10,522	2.0	20,955	31	293
13	30,100	5,570	190	5,455	0.29	18,900	0	0
		25.6	1.5	22.13		50	0	0
14	....	35,970	120	42,330	0.37	131,550	270	0
15	....	13,580	2,960	37,400	0.41	90,610	450	16
16	106,500	7.1	1.53	27	0.44	60.93	1	0.08
17	15,300	8.33	1.50	27.18	0.44	62.12	1	0.013
18	260,000	12.28	1.54	21.71	0.35	61.2	0.14	0.13
19	65,170	16,040	30	7,600	0.17	40,420		
20	126,319	7,440	2,960	37,026	0.49	78,800	tr.	41
21	35,817	1,779	464	11,146	0.55	20,007	2,086	313
22	35,000	420	1,300	11,100	0.57	19,410	2,700	72

NOTES TO TABLE IV

1. H. B. Riffenburg, "Groundwater of the Northern Great Plains," *U. S. Geol. Survey Water Supply Paper 560-B* (1925), p. 44; No. 7 from a well only 19 ft. deep; SE. ¼ Sec. 23, T. 6 N., R. 39 E., Rosebud County; Lance (Tertiary) formation; 8.8 SiO_2, 0.4 Fe., bicarbonate shown, trace NO_3.

2. *Op. cit.*, p. 44; No. 5, softened, deepest well (2,100 ft.); SW. ¼ Sec. 29, T. 154 N., R. 100 W., Williams County, North Dakota.

3. B. Coleman Renick, *Jour. of Geol.*, Vol. 32 (1924), p. 675, Table I, No. 1; SW. ¼ Sec. 10, T. 6 N., R. 41 E., Rosebud County; Lance formation; 12 SiO_2, 0.2 Fe, 5.5 H_2S, 24 CO_3, 669 HCO_3, trace of NO_3.

[1] *Trans. A. I. M. E.*, Vol. 61 (1920), p. 577.

4. *Op. cit.*, p. 675, Table I, deepest well (590 ft.); SE. ¼ Sec. 6, T. 6 N., R. 43 E., 15 SiO_2, 0.2 Fe. 9.6 CO_2, 1,169 HCO_3, trace NO_3.

5. A. W. Ambrose, "Analysis of Oilfield Water Problems," *Trans. A. I. M. E*, Vol. 65 (1921), p. 255., Table I, Record 5 of the East Side field, Coalinga, California, September, 1916; top water above marker, tar sand, and producing sands; figures are per cents of reaction value.

6. *Op. cit.*, p. 255, Table I, Sample 1, Shell well No. 31/34, 355 ft. below marker, just above producing sands, but below tar sands; no S.

7. *Op. cit.;* Sample 2, same well, 416–418 ft. below marker horizon; 11 per cent of reacting values S.

8. *Op. cit.;* Sample 3, same well, 429–438 ft. below marker; 14 per cent S.

9. *Op. cit.;* Shell well No. 10/2, 705–724 ft. below marker, and below producing oil zones, "bottom water."

10. G. Sherburne Rogers, "Chemical Relations of the Oil-field Waters in San Joaquin Valley, California," *U. S. Geol. Survey Bull. 653* (1917), p. 59, Table II, No. 9; normal ground water from the Coalinga field, Standard Oil Co. water well No. 2, depth 444 ft., Sec. 36, T. 19 S., R. 15 E.

11. *Op. cit.*, p. 69, Table VI, No. 34, surface water altered by action of oil, California Oilfields Ltd. well 5, Sec. 29, T. 19 S., R. 15 E.; sulphur water from 2,655 ft., a short distance above the oil zone; 26 H_2S, 86 SiO_2, 15 Fe_2O_3 and Al_2O_3.

12. *Op. cit.*, p. 73, Table VIII, No. 48, connate water altered by oil, from the oil zone in the Midway field, at 2,700 ft. in Standard Oil Co. well No. 6, Sec. 22, T. 31 S., R. 23 W.

13. Hudson and Taliaferro, *Amer. Assoc. Petrol. Geol. Bull.*, Vol. 9 (October, 1925), pp. 1075, 1078, 1079, Table I, No. 4, and Table III, No. 17, from 2,037 ft. in Harvey well No. 8, South Mountain field, Ventura County, California. Percentages given for No. 17.

14. E. I. Ickes, "Recent Exploration for Petroleum in the United Kingdom," *Trans. Amer. Min. Eng.* Vol. 70 (also No. 1279-P, issued with *Mining and Metallurgy*, October, 1923), p. 1074, Table II, No. 9, from 3,570 ft. in the Apedale well, which from 1,450 to 4,348 ft. was in a reddish basic, augitic Mississippian volcanic ash; 500 Sr, 270 K, 7 Li, 12 NH_4, 760 Br., 4 I.

15. *Op. cit.*, p. 1074, Table II, from bottom of Renishaw well (4,185 ft.); formation below 3,400 ft. was Pendleside limestone shales (Culm, possibly Mississippian). An analysis of a higher water at 3,198 feet with almost the same Na:Cl ratio is also given.

16. F. Reeves, *Johns Hopkins University Contributions to Geology* (1917), p. 65, deepest Pennsylvanian (1,600 ft.) brine cited; total solids and percentages of salts given.

17. *Op. cit.*, p. 65, average of eight Mississippian brines; total solids and percentages of salts given.

18. *Op. cit.*, p. 65, average of four lower Devonian brines, but these average 4,077 ft. deep as against 1,790 ft. for No. 17.

19. A. C. Lane, *Geol. Survey of Michigan, Pub.* 6 (1911), p. 838; about 900 ft. down in the Freda (Upper Keweenawan) sandstone. G. A. Koenig, *analyst.*

20. Roy O. Neal, "Petroleum Hydrology Applied to Mid-Continent Field," *Trans. A. I. M. E.*, Vol. 61 (1920), p. 567; a "top water" from the 1,660-foot sand in the Augusta field, as I interpret it, the most nearly connate of the analyses, with the lowest Na:Cl ratio and next to the highest amount of chlorine of any of the analyses.

21. *Op. cit.*, p. 571; a bottom water in the 2,450-foot sand, near an old unconformity?

22. Sea water cited by Neal from Palmer, given also in Clarke's "Data of Geochemistry," p. 127, from Dittmar's *Challenger Report.*

are selected, and therefore tend to prove its arguments, only in so far as they are typical of the many analyses from which they are taken. They will, however, serve to make the matter more concrete and understandable without reference to all the citations. In the tabulation only the six principal constituents are given. I have not used Chase Palmer's ingenious classification, because it groups potassium and sodium together and calcium and magnesium, pairs which, whatever their chemical and industrial likeness, have a very different geological rôle. The general arrangement is from the surface waters and those affected by permutit reactions to those with a larger amount of calcium chloride, but analyses from the same reference are kept together. The amounts are in grams per ton (parts per million) unless otherwise stated.

THE DISTRIBUTION AND CORRELATION OF THE MISSISSIPPIAN OF OKLAHOMA[1]

GEORGE S. BUCHANAN[2]
Tulsa, Oklahoma

ABSTRACT

The nomenclature of beds of Mississippian age in Oklahoma is confusing. By using two type sections, one in northeastern Oklahoma and the other in the area of the Arbuckle Mountains, and comparing these sections with the type eastern section, their stratigraphical relationship is much simplified.

The Kinderhookian, Osagian, Meramecian, and Chesterian groups are all well represented in Oklahoma. The Chattanooga shale and Woodford chert are stratigraphic correlatives and these beds mark the base of the Kinderhookian. The Osagian group is represented by the Boone limestone and chert of northeastern Oklahoma. Boone deposition was limited to a much smaller area than is generally realized. A big depositional and erosional break occurs between beds of Osagian and Meramecian age. Beds of Meramecian age were the most widely deposited beds of Mississippian age in Oklahoma. The following Chesterian deposition was largely restricted to northeastern Oklahoma.

INTRODUCTION

There is great need for detailed and careful study of the Paleozoic rocks of Oklahoma with a view to defining and simplifying nomenclature. Suggested correlations have found their way into many publications; fortunately, some correlations fell into obscurity almost immediately but others should remain in current usage.

It is not the purpose of the writer to attempt to show the stratigraphic relationship of all the Paleozoic beds of Oklahoma to those found elsewhere, but to make a careful survey of the published material of one particular period, the Mississippian, and to present these authoritative views with some of his own observations.

The Mississippian period has been chosen, not because of the wealth of accessible material, but because of the lack of an appreciation of the nature and character of the Lower Carboniferous of Oklahoma. It is the hope of the writer that this paper will act as a stimulus to further research and a better understanding of this particular period.

The Mississippian period will be discussed in groups, using, mainly,

[1] Read before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, August 24, 1927.

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[2] Consulting geologist, 1102 Atlas Life Building.

two type sections, one in the northeastern part of the state, and the other in the area of the Arbuckle uplift and northward (Fig. 1). A brief description will be given of the nature of the surface upon which Mississippian sediments were first laid down.

PRE-CHATTANOOGAN AREAL GEOLOGY

From Cambrian to mid-Devonian time, there was varied and interrupted sedimentation in the Oklahoma basin. Ozarkian, Canadian, and Ordovician deposits so filled the elastic portions of the basin that the later Silurian and Devonian seas were much restricted and confined (Fig. 2). By the end of Hunton deposition, equivalent to the Oriskany stage, the basin had been so completely filled as to approach a depositional plain. To account for the flat-lying surface upon which the succeeding Chattanooga shale was laid down, some writers have suggested that profound beveling erosion took place during the hiatus from the close of the lower Devonian to the beginning of the Mississippian. The only real evidence for severe erosion may be found in the Hunton limestone, made up of beds of Silurian and Devonian ages. In the last few years, many wells have been drilled in Pottawatomie, Seminole, Hughes, and Okfuskee counties, supposedly near the center of the Hunton basin. In offset wells, a great difference in the thickness of the Hunton limestone is found. In many places, it has been entirely removed without affecting the underlying Sylvan shale. The erosion of the Hunton limestone, which is a comparatively pure limestone, appears to have been of a chemical nature, since the clay shale below is present in its uniform thickness. Rather than profound mechanical erosion, resulting in peneplanation, the writer suggests that little lower Paleozoic erosion took place, but that there was sufficient infilling of sediments into a self-defined basin to form eventually a depositional plain. Upon such a surface widespread black shale conditions of sedimentation prevailed in lower Mississippian time.

KINDERHOOKIAN GROUP

Beds belonging to the Kinderhookian group in northeastern Oklahoma are the Sylamore sandstone, the Chattanooga shale, and the Choteau formation. In the Arbuckle mountain area, beds that may be assigned to this group are the Woodford shale and chert and the Sycamore limestone.

In the "Revision of the Paleozoic System," E. O. Ulrich[1] began the Mississippian with the Chattanoogan group, followed by the Kinder-

[1] E. O. Ulrich, "Revision of Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22, 1911.

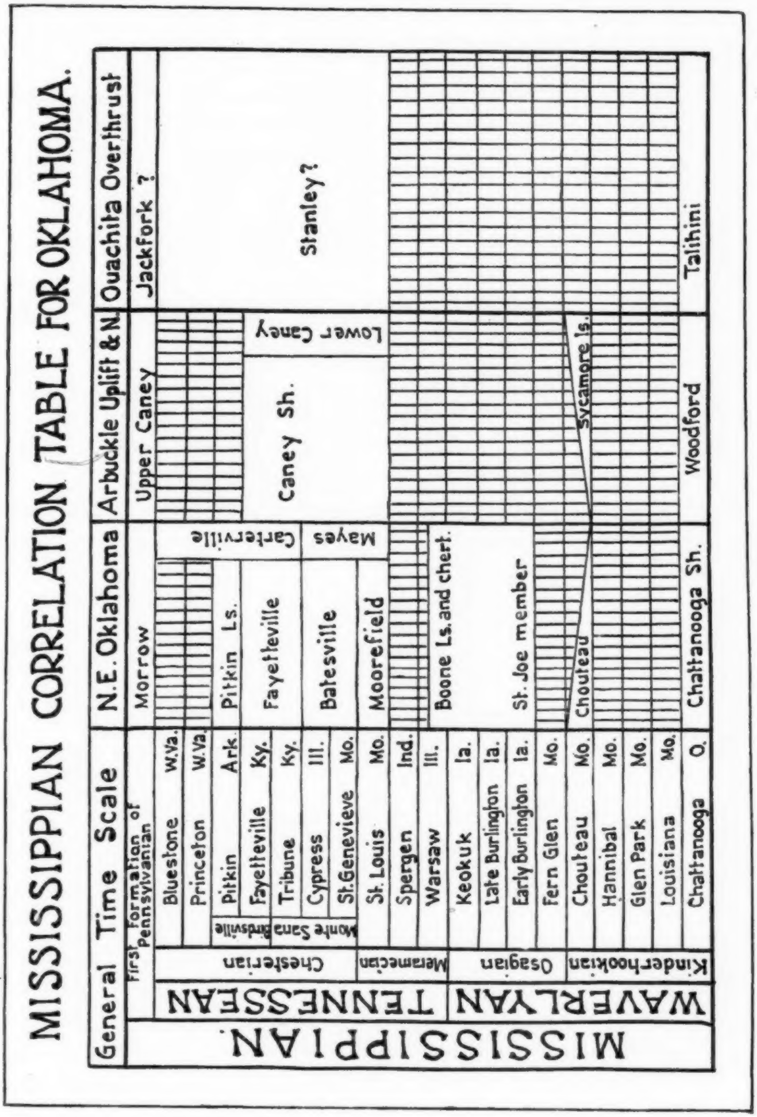

MISSISSIPPIAN CORRELATION TABLE FOR OKLAHOMA.
General Time Scale
N.E. Oklahoma
Arbuckle Uplift & N.
Ouachita Overthrust
First Formation of Pennsylvanian
MISSISSIPPIAN.
TENNESSEAN
WAVERLYAN
Chesterian
Meramecian
Osagian
Kinderhookian
Monte Sana
Birdsville
Bluestone W.Va.
Princeton W.Va.
Pitkin Ark.
Fayetteville Ky.
Tribune Ky.
Cypress Ill.
St. Genevieve Mo.
St. Louis Mo.
Spergen Ind.
Warsaw Ill.
Keokuk Ia.
Late Burlington Ia.
Early Burlington Ia.
Fern Glen Mo.
Chouteau Mo.
Hannibal Mo.
Glen Park Mo.
Louisiana Mo.
Chattanooga O.
Morrow
Carterville
Pitkin Ls.
Fayetteville
Mayes
Batesville
Moorefield
Boone Ls. and chert.
St. Joe member
Chouteau
Chattanooga Sh.
Upper Caney
Lower Caney
Caney Sh.
Sycamore ls.
Woodford
Jackfork ?
Stanley?
Talihini

Fig. 1

hookian group. Later work by him has shown that it would be advisable to include the Chattanooga as the black shale formation of the Kinderhookian (Fig. 1). Black Chattanooga shale conditions of deposition continued into beds of unquestionable Kinderhookian age.

Chattanooga shale deposition began locally with a sandy beach deposit, the Sylamore sandstone. The Sylamore is well represented in exposures near Tahlequah and Marble City in the Tahlequah quadrangle.

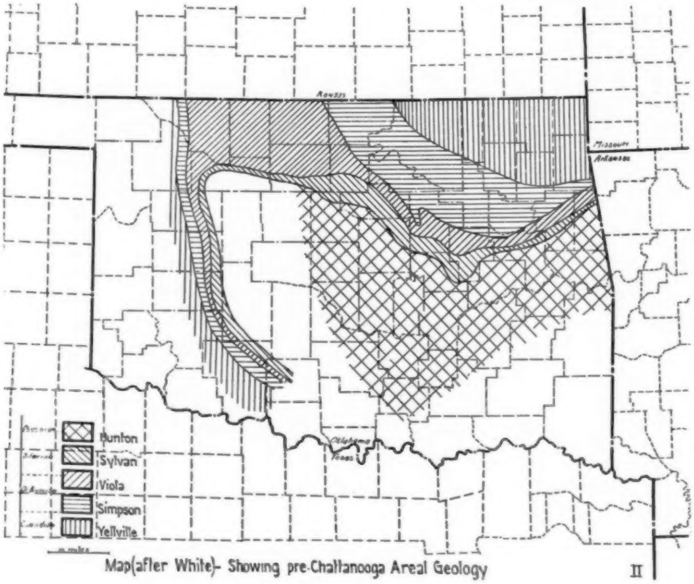
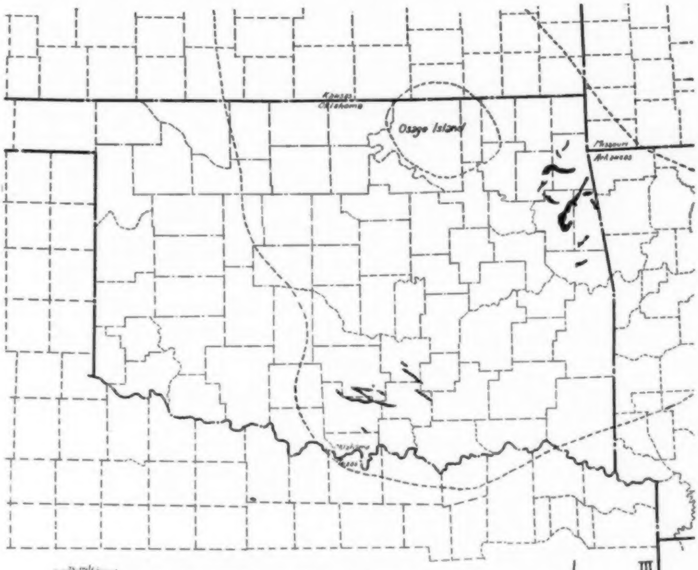


FIG. 2

It is extremely irregular in its occurrence but is found in many places at the base of the Chattanooga outcrops and generally less than a foot in thickness. The sandstone is in many places phosphatic and the sand grains are much pitted and frosted, suggesting the older St. Peter sandstone as the original source. The stratigraphic equivalent of the Sylamore in the Oklahoma basin is the Misener sand.

The black Chattanooga shale was deposited on the Sylamore sandstone with no apparent break. The uniform character, over a widespread area, of this clay humulith, and its rather constant thickness, which averages 40 feet but may attain more than 100 feet, is indeed singular.

The Chattanooga shale is exposed in northeastern Oklahoma in many places where the overlying Boone limestone has been removed by erosion. Much of this erosion occurred prior to Tennessean deposition. The Chattanooga is in Barren Fork valley south of Westville, in valleys south of Cowskin River, along Spavinaw and Spring creeks, in the bend of Illinois River north of Tahlequah, and at Marble City in Sequoyah County. Near the center of the Oklahoma basin, the Chattanooga shale is found in deep



Area of Chattanooga-Woodford Sea & Chattanooga and Woodford Outcrops

FIG. 3

wells resting on the Hunton limestone of Devonian age, but progressive overlap to positive and semi-positive areas such as Ozarkia caused the Chattanooga to rest on successively older beds. At Spavinaw, Oklahoma, the Chattanooga shale is resting on the Yellville formation of Canadian age. The probable limit of Chattanoogan deposition is shown in Figure 3. Samples taken from several wells drilled in Osage County show that the Chattanooga shale is absent. There is evidence that this absence is due to lack of deposition on a probable lowland mass which the writer has named "Osage Island." The Chattanooga shale increases in thickness toward the

area of the Arbuckle Mountains, where beds of the same age have been described under the name of Woodford chert.

The Woodford chert takes its name from the village of Woodford, Carter County, where it is made up of calcareous chert and black fissile shales in which many phosphate nodules occur. In the type area the average thickness is about 600 feet, but this thickness decreases rapidly toward the north. On the north side of the Arbuckle Mountains, the average thickness is about 200 feet and the Woodford here and northward into the Oklahoma basin is essentially free from chert. The Woodford occurs above the Hunton limestone around the periphery of the Arbuckle Mountains. It is exposed in Pontotoc, Murray, Johnson, and Carter counties.

As Girty[1] has pointed out, there has been much confusion in establishing the age of the Woodford. This has been due to the incomplete fossil evidence of the Woodford, the lithologic similarity of the overlying Caney shale, and the absence, in many places, of the intervening Sycamore limestone. It is difficult in the field to establish the top of the Woodford shale and the base of the Caney. As a result, some collections reported as from the Woodford have in reality been from the lower Caney shale. Probably the best fossil evidence of the age of the Woodford is its rich content of Mississippian conodonts and the plant spore, *Sporangites huronense*. Identical spores and the same species of conodonts are present in the Chattanooga shale, and a recent collection by Roth,[2] from the Talihini chert of the Ouachita area, established the presence of Mississippian conodonts in the upper part of the chert. Miser[3] has already suggested the correlation of the upper part of the Talihini chert with the Woodford on the basis of lithology.

It would seem, then, that in the Ouachita area and the Arbuckle area, Chattanoogan deposition is represented not only by black mud deposition but by large masses of calcareous chert. This siliceous phase of Chattanoogan deposition was localized, since there has been no chert found anywhere in the shales north of the Arbuckle Mountains.

The upper part of the Kinderhookian is locally represented in northeastern Oklahoma by the Choteau formation. At the base of the Boone formation along Illinois River and in the Tahlequah quadrangle, are beds of argillaceous limestone assigned to the Kinderhook and correlated with

[1] George H. Girty, "Fauna of the Caney Shale of Oklahoma," *U. S. Geol. Survey Bull.* 377 (1909), p. 12.

[2] Personal communication.

[3] Personal communication.

the Choteau of southwestern Missouri by Snider.[1] These beds in places attain a thickness of several feet but seem to be absent farther west.

In many places, a bed of green glauconitic shale, having a maximum thickness of only a few feet, is below the Boone and above the Chattanooga shale. From its stratigraphic position and because of its lithologic character, this bed may be of Kinderhookian age. A little farther west in the Oklahoma basin, the Boone is absent and much younger Mississippian beds are resting on the Chattanooga. Well samples from this area show a very similar green shale at this contact, which may also represent a Kinderhookian deposit.

In the Arbuckle area the upper Kinderhookian is represented by the Sycamore limestone. Its type locality, Sycamore Creek, is in western Johnson County. The occurrence of the Sycamore limestone in the Arbuckle Mountains is also peripheral and is just outside the Woodford ridge previously mentioned. It has been described by Taff[2] as a lentil because of its wedge shape. On the southwestern flank of the Arbuckle Mountains, the Sycamore limestone has a thickness of nearly 200 feet. On the northeastern side of the Arbuckle Mountains, it is generally less than 5 feet thick and thins rapidly until it disappears a score of miles from its outcrop. The Sycamore at its outcrop is a hard, granular, blue limestone which weathers to a light yellow. A considerable amount of glauconite is included in the limestone. Farther north from the area of the outcrop in the Oklahoma basin, the contact of the Caney and Woodford shales may be observed from well samples. Here the Sycamore limestone is generally absent, but at the contact are a few feet of greenish glauconitic shale already mentioned under the description of the Choteau formation.

After examining a collection of fossils in the Sycamore limestone, Schuchert[3] was satisfied that it represented a Kinderhookian fauna. On the basis of a recent collection, Raymond C. Moore[4] is of the same opinion. Following the Sycamore deposition is a long hiatus in the Arbuckle area. Attention must be turned to northeastern Oklahoma where Osagian deposition follows the Kinderhookian.

[1] L. C. Snider, "Geology of Northeastern Oklahoma," *Okla. Geol. Survey Bull. 24*, 1915.

[2] Joseph A. Taff, "Geology of the Arbuckle-Wichita Mountains in Indian Territory and Oklahoma," *U. S. Geol. Survey Prof. Paper 31* (1904), p. 33.

[3] Charles Schuchert, quoted by George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Oklahoma Bureau of Geology, Bull. No. 2* (1924), p. 50.

[4] Personal communication.

OSAGIAN GROUP

The Osagian group includes beds of the Boone formation. For the most part, it is essentially the same as the Boone of Missouri and Arkansas, consisting of chert and limestone with limestone predominating toward the base.

In Oklahoma, the Boone formation outcrops in Delaware and Adair counties, in southwestern Ottawa and Craig counties, the eastern half of Mayes County and the northwest part of Cherokee County. There are excellent exposures along the banks of Grand River in Mayes County.

The base of the Boone formation where it is exposed shows a noncherty limestone member which may be locally absent or may be 100 feet thick. This member was described by Taff in the Tahlequah quadrangle report, and he correlated it with the St. Joe limestone member of the Boone formation of Arkansas. The fauna of the St. Joe member indicates its early Burlington age.

The chert member makes up the greater part of the Boone formation and consists of interbedded chert and limestone. This member ranges in thickness from 100 feet to 350 feet. A probable explanation of the origin of such a massive cherty body is well discussed by W. A. Tarr.[1]

The lower portion of the chert member contains late Burlington fossils and the more fossiliferous upper portions contain a Keokuk and early Warsaw fauna.

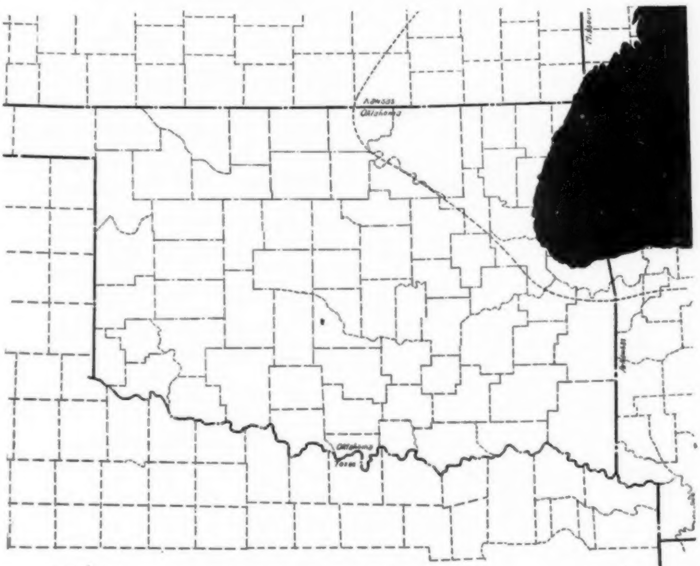
The probable area of Boone deposition in Oklahoma is much smaller than is generally considered (Fig. 4). The formation thins rapidly from the area of outcrop toward the west and southwest. The total absence of Osagian deposition in the area of the Arbuckle uplift and northward in the Oklahoma basin is of vast significance.

Following Kinderhookian deposition, there was a general emergence of the Arbuckle Mountain area and the area northward in the Oklahoma basin. In northeastern Oklahoma, however, was an area that belonged to the Ozark submergence and consequent deposition during the Osagian epoch. Subsequent to this epoch of siliceous sedimentation, there is evidence of considerable orogeny. The Ozark mass again emerged, and accompanying this general uplift there was much complex folding and faulting. The following Meramecian beds consequently had a very uneven, folded, faulted, and eroded platform upon which they might encroach. Elevation at the close of the Osagian in the Ozark area was accompanied by a general depression elsewhere in Oklahoma.

[1] William Arthur Tarr, "The Origin of Chert and Flint," *University of Missouri Studies*, Vol. 1, No. 2, 1926.

MERAMECIAN AND CHESTERIAN

These two groups include beds so closely related in character and manner of sedimentation that they will be discussed together. Excepting a local deposition of the Boone chert and limestone in eastern Oklahoma, the Mississippian preceding and also succeeding Boone sediments are essentially beds let down under black shale conditions. The significance of the persistence of the black shale conditions over a wide area extending from Devonian to Pennsylvanian time, has been emphasized by Girty.[1]



Area of Boone Sea & Boone Outcrops IV

FIG. 4

In the eastern section of the state, immediately above the Boone and resting disconformably on it, is the Mayes formation. It was described by Snider[2] and he gave as the type locality Mayes County, Oklahoma. The Mayes is made up of interbedded black shales and black, sandy, micaceous, and argillaceous limestones. Around the margin of the Boone lime-

[1] G. H. Girty, "The Fauna of the Moorefield Shale of Arkansas," *U. S. Geol. Survey Bull. 439* (1911), p. 24.

[2] L. C. Snider, *Oklahoma Geological Survey Bull. 23* (1915), p. 27.

stone, where the Mayes outcrops, the thickness ranges from 3 feet to 100 feet. The formation increases appreciably in thickness westward to the center of the Oklahoma basin. This formation has been known for years as the black Mississippian limestone. It was first shown to be of younger age than the Boone by Aurin, Clark, and Trager.[1] Westward from the limits of Boone deposition, the Mayes is found in contact with the Chattanooga shale. The Mayes formation may be correlated with the Moorefield shale and the Batesville sandstone of Arkansas and with a part of the Caney shale of the Arbuckle area, of which more will be said later.

CANEY SHALE

The type locality of the Caney shale is in the valley of Cane Creek in northwest Pushmataha County. Unfortunately, the type Caney shale is of Pennsylvanian age as shown by Ulrich. After naming and describing the type Caney shale, the same name was applied to black shales of Mississippian age. It is with these shales that we are most familiar because of their wider occurrence, their greater accessibility, and their common mention in literature. In fact, the name Caney shale is so strongly imbedded in the minds of many as referring to a shale of Moorefield age that it would seem advisable to change the type locality to one of Mississippian age in the Arbuckle Mountain area and give a new name to those isolated patches of Pennsylvanian "Caney" shale. The term Caney, as here used, refers only to Mississippian sediments. It is exposed on the flanks of the Arbuckle uplift in Pontotoc, Johnston, Murray, and Carter counties. The Caney is also well represented in exposures along the northern extremities of the Ouachita overthrust in Atoka, Pushmataha, Pittsburg, Latimer, and Le Flore counties (Fig. 5).

The lower portion of the Caney consists of brown to limy black shales, in many places micaceous. The upper part of the Caney consists of brown to black micaceous shale with a few limy shale beds.

The Caney, or Mayes, may be traced northward by actual continuity of well samples from the area of outcrop in the Arbuckle Mountains to the Seminole area, to the Chandler area, and to the area near Stillwater. Throughout this entire distance, the Mayes maintains its peculiar lithologic character with the exception that in the vicinity of Stillwater the upper part of the formation is much lighter gray in color. Northward from Stillwater toward the Kansas line, this upper gray portion becomes

[1] F. L. Aurin, G. C. Clark, and Earl A. Trager, "Notes on the Subsurface Pre-Pennsylvanian Stratigraphy of the Northern Mid-Continent Oil Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 2, 1921.

siliceous. In this area the drill encounters 30 or 40 feet of cherty lime below which is the characteristic black limy shale. The chert very closely resembles the upper portion of the Boone formation with which it has been correlated. These cherty beds are very much younger than Boone and may be accounted for by assuming different conditions of sedimentation in north-central Oklahoma in Meramecian and Chesterian times,

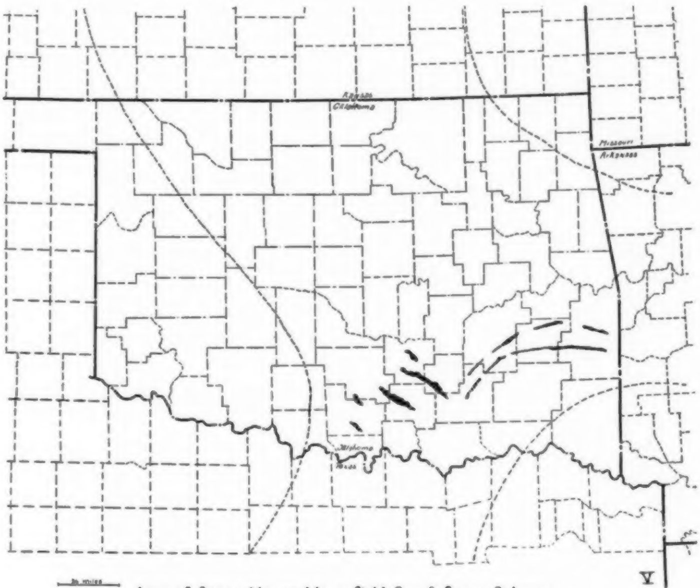


Fig. 5

from the conditions prevailing in south-central Oklahoma and the eastern part of the state. It has been suggested that this cherty part of the Mayes represents early Pennsylvanian deposition. But it has been brought to the writer's attention that in many places there is a gradational change from black limy shales upward to gray limy shales and from gray limy shales to the massive chert beds. This evidence and the fact that the chert in many places was entirely removed by erosion prior to unquestionable Pennsylvanian deposition, is strongly suggestive of Mississippian-Pennsylvanian orogeny.

The lower Caney and the Mayes already described are lithologically and faunally very similar to the Moorefield of Arkansas.[1]

Overlying the Moorefield in Arkansas and the Mayes in Oklahoma, are the Fayetteville shale and Pitkin limestone. The areal extent of beds laid down in Fayetteville and Pitkin times is much less than the area of the preceding Mayes. The partial withdrawal of the Pitkin sea into a well-defined basin in Oklahoma marks the close of Mississippian deposition. The Fayetteville shale, although laid down under the prevailing black shale conditions already mentioned, shows the introduction of typical Chester fossils of the eastern section. The peculiar fauna common to the Caney, to the Mayes, and to the Moorefield shale of Arkansas, and represented elsewhere in southwestern United States, suggests a north Pacific invasion during upper Mississippian time. This fauna is not known in our type Mississippian section in the eastern United States, nor is it known in western Europe. It has been brought to the writer's attention that this peculiar Mississippian black shale fauna is represented in the Lower Carboniferous of Asia. In a general way, the area of the Ozark uplift acted as a barrier to a farther eastward invasion of that sea. Indeed, the Fayetteville shale of Arkansas and Oklahoma suggests the time of the first connection of Chester seas across a portion of this barrier. The Fayetteville is composed essentially of black calcareous shales with a few interbedded limestone members similar to the limestone beds in the Mayes. It outcrops between the Mayes limestone below and the Pitkin limestone above along the margin of the Ozark Mountains. A paleogeographic map of Fayetteville and Pitkin seas is shown in Figure 6.

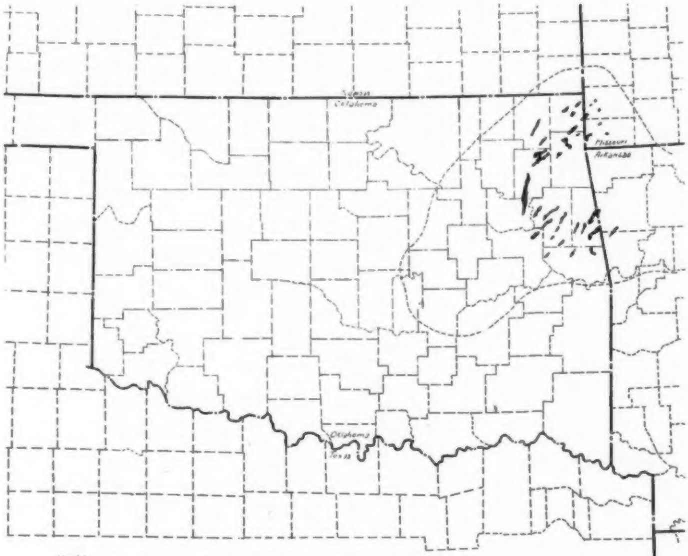
The Pitkin limestone, which is conformable on the Fayetteville, is the uppermost deposit of Chester age. It outcrops in many patches around the margin of the Ozarks above the Fayetteville shale. Taff's description is as follows: "The Pitkin limestone varies from rusty brown, granular, earthy and shaly strata at one extreme to fine-textured bluish beds at the other. Blue clay shale locally occurs interbedded with the limestones."[2]

Toward the southwest, the Pitkin limestone becomes more and more sandy. The quartz grains are undoubtedly re-worked Simpson sand grains and their source was from the southwest beyond the borders of the Pitkin sea in the Arbuckle-Wichita area. Lithologically, and faunally, a

[1] G. H. Girty, "The Fauna of the Moorefield Shale of Arkansas," *U. S. Geol. Survey Bull. 439*, 1911.

[2] J. A. Taff, "Geology of Tahlequah Quadrangle," *U. S. Geol. Survey, Geologic Atlas, No. 122.*

close relationship seems to exist between the Pitkin limestone of Chester age and the Wapanucka limestone of Pottsville age. The writer suggests that the Chester sea never completely withdrew from Oklahoma but that the Pottsville invasion from the southwest introduced new Pennsylvanian forms at a time when the Chester forms were evolving. An intermingling of faunas and a transitionally changing fauna have been responsible for much of the confusion. As Kirtley Mather[1] suggests, there is a residual



Area of Pitkin-Fayetteville Sea & Pitkin Outcrops VI

FIG. 6

and proemial element in the fauna. That movement occurred in the Ozark area near the end of Pitkin time is strongly suggested. The area of thick limestone deposition of late Chester time was shifted considerably southward in early Pottsville time as shown by the position of the area of thick Wapanucka limestone. The sandy phases of the Morrow which are correlated with the Wapanucka limestone indicate an eastern as well as a southwestern source for the sand and evidence of uplift in the Ozark area.

[1] Kirtley F. Mather, "The Fauna of the Morrow Group of Arkansas and Oklahoma," *Bull. of the Scientific Laboratories of Denison University*, Vol. 18 (1915), p. 67.

The relationship of probable Mississippian sediments of the area of the Ouachita overthrust to the beds that have been discussed in the two type areas of this paper is not well defined. The problems in connection with the Ouachita overthrust are scarcely appreciated.

STANLEY-JACKFORK

In the correlation table given in this paper, the Stanley shales have been tentatively placed in the upper Mississippian. These clay shales, approximately 6,000 feet thick, are exposed throughout a large part of the Ouachita Mountains. They represent both marine and terrestrial deposition and, from their character and thickness, suggest enormous delta and fanlike deposits. The muds seem to have been derived from a land mass at the south, possibly in the area of the Sabine uplift. The greatest objection to placing the Stanley shales in the upper Mississippian has been due to a superposition of Caney upon Jackfork and Stanley beds in the Ouachita area. Girty[1] suggests the difficulty in assuming such a thickness of strata as the Stanley shales laid down in upper Mississippian time below the Caney which he has already established as upper Mississippian. This difficult problem has been solved by Ulrich, who has shown that this Caney was the type Caney and of Pennsylvanian age rather than Mississippian. It seems plausible that during Caney time deposition wholly marine in nature was taking place in the Oklahoma basin, while at the southeast the shoreward phase of this deposition is represented in part by the Stanley shales. The Jackfork sandstone immediately overlying the Stanley probably represents very early Pennsylvanian sediments, or very late Mississippian, or both. A petrographic study of the Jackfork with a study of the lower Pennsylvanian sandstones in the coal basin of Oklahoma would undoubtedly throw much light on the true position of the Jackfork.

[1] G. H. Girty, "The Fauna of the Moorefield Shale of Arkansas," *U. S. Geol. Survey Bull. 439*, 1911.

GEOLOGY AND PETROLEUM POSSIBILITIES OF THE OLYMPIC PENINSULA, WASHINGTON[1]

R. H. PALMER[2]
Seattle, Washington

ABSTRACT

The Olympic Peninsula is located in the extreme northwestern part of the United States. Extensive forests, logged-over areas, glacial deposits, and scarcity of roads hinder geological investigation. The geological column is limited to the Oligocene, Miocene, Pleistocene, and possibly Eocene. Much superficial folding and faulting occur along the coast. In the lower shale member of the Miocene, there are many gas and two oil seeps. The oil possibilities are worthy of investigation and test wells are proposed.

GEOGRAPHIC AND TOPOGRAPHIC FEATURES

The Olympic Peninsula lies in the extreme northwestern part of the United States. Its areal extent is about 60,000 square miles. The area investigated and the district to be discussed occupies the northwestern part of the peninsula. Parallel 124 and Meridian 48 intersect a few miles east of its center (Fig. 1).

The Olympic Highway passes from east to west from Port Angeles to the coast through the center of the area. Branch roads to Crescent Bay and Clallam Bay and a few trails afford the only other avenues of access.

The country is covered by a series of dense conifer forests, interspersed with logged-over, burned, and blow-down areas. This, combined with the mantle of glacial débris, obscures the underlying rocks except where exposed along the coast and rivers and in the highway and logging road cuts. Geological work is further hindered by the dense underbrush and by the bad weather of the rainy season, the yearly total precipitation commonly amounting to eleven feet.

Much credit is due to Arnold, Hannibal, Reagan, and Weaver for the pioneer work done in this region before the highway and logging roads afforded even the limited present-day facilities for geological investigation.

The northwestern part of the peninsula is a rolling plain dominated by the Olympic Mountains, from which it slopes westward to the Pacific

[1] Presented before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, August 19, 1927.

[2] 1825 Third Avenue, West, Apt. B.

Ocean and northward to the Strait of Juan de Fuca. Geologically it is a base-leveled plain that has been elevated and dissected. Near the coast the elevation is about 200 feet. In the vicinity of the Olympics the elevation is much greater, amounting to 5,000 feet. Mount Olympus is 7,900 feet high, and around this there are several peaks that are somewhat lower. Except for the peaks and ridges, the northern slopes of the moun-

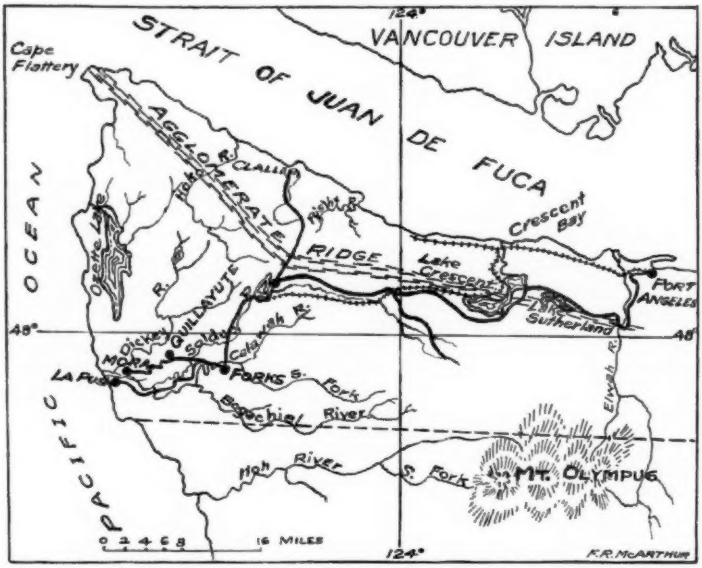


FIG. 1.—Map of northwestern part of Olympic Peninsula. The rocks of the terrain are for the most part of Miocene and Oligocene age. The Lake Crescent anticline has exposed the deeper igneous rocks of Agglomerate Ridge. These rocks are probably also Tertiary.

tains are covered by glaciers and snow fields down to an altitude of 4,500 feet. From the central mass several interstream ridges extend westward to the coast. Another ridge independent of the mountain range trends westward from Elwha River past Lake Crescent and thence northwestward to Cape Flattery, a distance of 55 miles. This is an extensive anticlinal structure, which may be referred to as the Lake Crescent anticline, on the north flank of which are exposed 50,000 feet of sediments and flow material. Peaks along this ridge have elevations as great as 4,600 feet. This ridge is largely a basaltic agglomerate, and with the exception of a

few basaltic agglomerate lenses seen along the coast, is the site of practically all the igneous rocks in the area. For reference this will be referred to as Agglomerate Ridge. These are the main topographic features and are under structural control.

The minor features are both structural and erosional. The short elongated hills near the coast with variously oriented axes are examples of the former and the canyons, flood plains, and sea cliffs illustrate the results of erosion.

Crescent, Sutherland, and Ozette are the principal lakes in the area. The first two are due to extensive landslides that dammed former drainage channels and the latter evidently to a local depression.

FIG. 2.—Headlands faced by reefs and islands and backed by inland ridges

The coast is broken by a series of inlets and headlands (Fig. 2). The headlands are faced by off-shore reefs and islands and backed by ridges that extend inland, suggesting structural conditions.

There are two flat treeless areas of a few square miles in extent known as the Forks and Quillayute Prairies.

STRATIGRAPHY

The oldest sediments known anywhere in the area are exposed at the east end of Lake Crescent in the south limb of the Lake Crescent anticline. These comprise about 200 feet of sandy shales the age of which is unknown, though they are probably Tertiary. Above them are 7,000 feet of basic agglomerates and basaltic flows. Resting in turn, evidently conformably, upon these, and extending to the Strait of Juan de Fuca, are 43,000 feet of sediments which, for the most part, consist of soft organic shales, though near the top the series becomes sandy and even contains sandstone lenses. It is interesting to note that the total thickness of this section from Lake Crescent to the strait is nearly $1\frac{1}{2}$ miles greater than the thickness Schuchert ascribes to the entire Paleozoic deposition.

The upper part of this thick series is the Clallam formation of upper Miocene age, the only member whose age is known. It is possible that the series extends down into the Oligocene and even into the Eocene, since the former is known to be present and the latter reported along the Strait of Juan de Fuca.

No older rocks have been found, though cherts are reported to occur which bear a close similarity to those of the Franciscan series (Jurassic ?) of California.

TABLE I

GEOLOGICAL COLUMN, BETWEEN HOH RIVER AND AGGLOMERATE RIDGE

System	Series	Formation	Thickness in Feet	Lithology	Correlation
Quaternary	Pleistocene		6–30	tan clay	
			0–100	glacial outwash	
			0–50	unstratified till	
Tertiary	Miocene	Quillayute	50	blue-gray sh. & soft ss.	Upper Empire
		Hoh	?	green-gray shale	?
			?	fretted ss.	?
			2,000	blue-gray sh. with cgl. lenses	Clallam Temblor
			250	soft gray ss.	
	Oligocene ?			gray sh. with cgl. beds "smell muds"	*Thyasira bisecta*, *Phacoides acutilineatus*; *Foraminifera*. Not older than Oligocene

The reported occurrence of older igneous and metamorphic rocks in Agglomerate Ridge and in the Olympic Mountains has not been checked. Their absence in the north slopes of the Olympics and in the boulder content of the streams heading in those areas indicates that, if they do occur, they are of very limited extent.

On the south side of the Lake Crescent anticline the somewhat different conditions of sedimentation produced deposits of a slightly different nature. To these Weaver has applied the name Hoh formation. This is divisible into four or five members as previously indicated (Table I). The lowest consists of a soft organic gray shale. It has a large areal extent and

is of unknown thickness, as its base is nowhere exposed. Within this member are a few sandstone and conglomerate beds. It probably directly underlies the Pleistocene in most of the areas of low elevation as well as the embayments along the coast. Nearly everywhere, during the rainy season, exposures of this shale yield a strong kerosene odor, whence it has received the local name of "smell muds." There are many gas seeps with petroleum odor in this member and on the north side of Hoh River there are two notable seeps of light oil. Many small lenses of asphaltum balls are scattered through this member. These appear to be residuary from former local accumulations of petroliferous material. It seems probable that the petroleum possibilities of the Olympic Peninsula are limited to this member.

Unfortunately no definite characteristic fossils are at hand to define accurately the position of these shales in the geologic column. However, the presence of *Thyasira bisecta* and *Phacoides acutilineatus* preclude its being older than Oligocene. In addition it contains several other forms of mid-Tertiary type and locally numerous *Foraminifera.*

Wave erosion is very effective against this soft shale and its presence along the coast is marked by embayments.

The thin soft gray sandstone above contains many traces of vegetable material between the bedding planes.

The next member is a hard blue-gray sandstone with extensive conglomerate lenses which seem to be confined to a few miles inland from the coast. The sandstone weathers to a rather characteristic tan-brown. This and the overlying fretted sandstone very effectively resist the erosive action of the waves, and the aforementioned bold headlands and off-shore reefs and islands mark their presence (Fig. 2). The folding of these beds with the underlying relatively incompetent soft shales results in such great irregularities that definite quantitative figures on the thickness of this member are not known: 20,000 feet is given as a tentative approximate measurement.

Fossil evidence definitely locates this member in the stratigraphic column at about the same place as the Clallam formation. The latter is of middle Miocene age and is correlated with the Temblor formation occurring along the Kern River, California, an important petroleum horizon of that state.

A greenish-gray shale occurs locally along the coast geographically near the sandstone-conglomerate member, which suggests close stratigraphic relations. However, its position in the section is as yet uncertain.

The uppermost known member of the Hoh formation is the Fretted

sandstone (Fig. 3). Complicated folding and faulting have obscured its relation to the sandstone and conglomerate below. It seems, however, that it is stratigraphically close and may even represent the upper part of that member. This is massive in structure and its attitude is such that definite measurement of its thickness has not been made.

The Quillayute formation occupies a limited area near the junction of the Solduc and Bogachiel rivers. It is a soft slate-gray sandstone locally carrying a plentiful upper Miocene fauna. It has been but little disturbed and is probably not more than 50 feet thick.

FIG. 3.—Fretted sandstone. The fretwork is in effect fossil checks. These small fractures on being "healed" by calcite became relatively more resistant than the intervening areas which later were excavated by wind erosion.

The Pleistocene consists of a small amount of till covered by an extensive mantle of glacial outwash. Along the coast and a few miles inland the outwash gravel is covered by a few feet of yellow clay that carries a few *Foraminifera* and fish teeth, indicating deposition in a shallow embayment of the sea. This clay covers the surface of both the Forks and the Quillayute Prairies.

STRUCTURE

The dominating geological structure of the part of the Olympic Peninsula under discussion is the Lake Crescent anticline. It is along the axis of this structure that the agglomerates and flows of Agglomerate Ridge are exposed. A fault with a throw of 1,500 feet or more at Lake Crescent parallels the axis. The north limb of this anticline dips regularly

to the north as far as the Strait of Juan de Fuca, which occupies the complementary syncline. These two structures are notable, as they are roughly at right angles to the Cordilleran structural trend. This phenomenon has a counterpart in the east-west axis of the Santa Barbara Islands and Channel and in the mountain ranges in southern Oaxaca, Mexico.

Paralleling this structure on the south are the structural ridges extending from the Olympic Mountains to the coast and several smaller ridges of minor importance. The folding here was of much less magnitude than along the Lake Crescent anticline, with the result that the gray shales are the lowest member of the series exposed. It is believed that in any investigation for petroleum in this region these structures should be considered. Near the coast lateral pressure from the southwest has complicated the western ends of these folds. However, two well-defined anticlines are in evidence along the coast where it is proposed to drill test wells.

It is a notable fact that, although there has been much folding and faulting, there is exposed but a limited geological column. For example, between Hoh River and the Lake Crescent anticline, 45 miles to the north, there are probably not exposed more than 4,000 feet of sediments. This condition suggests that the folding and faulting are superficial phenomena.

On the Quillayute Prairie test holes located in rows along a low east-west ridge nearly a mile in extent and sunk through the clay to the gravel show that the contours of these formations are parallel. This indicates that this ridge is of structural origin. In other words, it is the surface indication of an upward movement, and its magnitude is but the measure of this movement since the Pleistocene deposition of the clay and gravel. This condition, together with the presence of the gray shale in the vicinity, seems to warrant the drilling of a test well.

PETROLEUM POSSIBILITIES

The Olympic Peninsula has long been known to have petroleum possibilities. In 1914 Lupton[1] published a general report on the region in which he recounts the then known occurrences of oil and gas and the developments up to that time and also mentions several structures. In his conclusion he states: "The writer does not predict that oil will be found in commercial quantities in this field, but he firmly believes that it is a

[1] C. T. Lupton, "Oil and Gas in the Western Part of the Olympic Peninsula, Washington," *U. S. Geol. Survey Bull. 581-B*, 1914.

region worthy of the attention of oil operators."[1] This is a fair statement with which the writer agrees.

The decline of some fields and the exhaustion of others elsewhere, together with the tactical location of the Olympic Peninsula with reference to the market afforded by the Northwest, which is at the present time far removed from production, gives added importance to this region as a potential producer of petroleum.

[1] *Op. cit.*, p. 80.

GEOLOGICAL NOTES

MISSISSIPPIAN CORALS FROM A CENTRAL KANSAS WELL

An unusual collection of fossils from a deep well has recently come to the writer's attention through the kindness of Mr. William Ainsworth and Mr. John Winters of Wichita, Kansas. The well from which the fossils were obtained is the Ucker No. 1, drilled by Winters & Harwood in SW., SE., SW. ¼ of Sec. 2, T. 17 S., R. 4 E., Marion County, Kansas. After passing through Permian and Pennsylvanian strata which there overlie the west flank of the Nemaha granite ridge, the drill encountered a zone of white to cream yellow, more or less porous chert, corresponding closely in appearance to the Welch chert of counties farther west.[1] Blue-green clay shale was encountered at the base of the chert, and the well continued in this, 10 feet to the bottom. The depth to the top of the greenish shale according to the log is 2,466 feet, but correction by steel-line measurement shows the true depth to be 2,442 feet. Casing was set in the chert at 2,341 feet (corrected measurement).

The fossils that have been mentioned were obtained by Mr. Winters from clay shale sticking to the bit and in material brought up in the bailer, both representing depths of 2,442 to 2,447 feet (corrected measurement). Hence they occur at the very top of the greenish shale or base of the overlying chert. It is rather surprising to find that the entire lot of a dozen or more specimens includes only small horn corals belonging to two species, *Zaphrentis calceola* White and Whitfield, which is the more plentiful, and *Zaphrentis tenella* Miller. The collection contains some complete, perfectly preserved individuals about 15 millimeters in length and fragments of larger specimens. The peculiar flattening especially in the apical region of the convex portion of the corallum; the strong, unevenly spaced cinctures that are much more prominent than in most rugose corals; and the number and arrangement of the septa, with strong cardinal fossula on the convex side, are all characteristic of *Z. calceola*. The specific features that distinguish *Z. tenella* are likewise well shown. Precise identification is aided by the presence in collections of the University of Kansas and of the writer of a large number of well-preserved examples of these and other associated species.

[1] Raymond C. Moore, "Early Pennsylvanian Deposits West of the Nemaha Granite Ridge, Kansas," Vol. 10 (1926), pp. 205–16.

Both of the zaphrentids thus recognized in the Ucker well were originally described from a zone, mainly distinguished by its interesting coral fauna, that occurs at the top of the Chouteau limestone, as defined in the older Missouri reports, near Sedalia, Missouri. Associated with the corals are several other species, most of which are unknown from any other horizon. Some of these are *Chonophyllum sedaliense*, *Leptopora typa*, and *Hadrophyllum glans*. Stratigraphic studies by the writer have shown that this coral zone is traceable to northeast Missouri and Iowa, and is apparently well represented also in magnesian limestone beds found in southwestern Missouri. Faunal and stratigraphic evidence indicates, in the writer's belief, that the so-called "upper Chouteau" of the literature is an initial Osage deposit, most closely related to the Fern Glen and Lower Burlington rather than the Kinderhook, and it is given the name, Sedalia limestone.[1] The early Osage deposits appear to have been very widespread, being known from Alabama[2] on the southeast to the Lake Valley region in New Mexico[3] or beyond. It is interesting to find proof of the presence of the Sedalia coral fauna, of earliest Osage, in Marion County, Kansas.

An important problem that is brought to attention by the discovery of these fossils is the age of the Welch chert and of the shale which is found beneath the chert in many parts of central Kansas. Except weathered crinoid stems and unidentifiable organic remains, no fossils have been found in the Welch chert. The discovery of numerous Pennsylvanian fossils in blue shale beneath the Welch chert in the Keys Sheridan or Carneiro well, Sec. 21, T. 15 S., R. 6 W., Ellsworth County, has been described by the writer[4] and interpreted as evidence of the Pennsylvanian age of the chert, which was thought to have been derived from exposed Mississippian and older rocks in bordering areas. Search for fossils in the corresponding shale zone of other wells has been unsuccessful in corroborating or disproving the implications of the Sheridan well fossils. The corals from the Ucker well at a horizon immediately below chert that seems to correspond to the Welch zone are clearly of early Mississippian age and presumably indicate that the greenish clay shale containing them was deposited about the same time as the coral-bearing limestone of central

[1] Raymond C. Moore, "Early Mississippian Formations in Missouri," *Missouri Bur. Geol. and Mines*, in press.

[2] Charles Butts, "The Paleozoic Rocks, in Geology of Alabama," *Alabama Geol. Survey*, Spec. Rept. 14 (1926), pp. 162–67.

[3] Stuart Weller, "Kinderhook Faunal Studies V. Fauna of the Fern Glen Formation," *Bull. Geol. Soc. Amer.*, Vol. 20 (1910), pp. 326–27.

[4] Raymond C. Moore, "Early Pennsylvanian Deposits West of the Nemaha Granite Ridge," *Amer. Assoc. Petrol. Geol. Bull.*, Vol. 10 (1926), pp. 209–10.

Missouri that is assigned to the very top of the Kinderhook or base of the Osage group. This conclusion is supported by the considerable number of specimens, a dozen or more, contained in the Ucker well samples and by the absence of fossils of other stratigraphic relations. However, one observes that several of the specimens are markedly weathered and rolled. In some, not only is the theca entirely removed but the borders of the calyx are so worn down that the edges of the septa project strongly and in one specimen the coral is flattened by abrasion until only about one half of the original fossil remains. Other specimens are complete and apparently fresh. The condition of the imperfect fossils is very obviously a result of vicissitudes preceding or attending their burial in the sediment that now contains them and is not due to action of the drill.

Consideration of all the evidence leads to the conclusion that the green clay is of early Mississippian age essentially corresponding to the designated coral-bearing beds near Sedalia in central Missouri. The overlying chert occupies the stratigraphic position and possesses lithologic characteristics that suggest the "Mississippi lime," which is equivalent to the Boone formation of the southwestern Ozark region. Whether this chert in the Ucker well is exactly equivalent to the Welch chert in Rice, Reno, and neighboring counties or whether it is in part the source of the Welch chert is a question not settled by the fossil evidence here presented. The lithologic peculiarities of the Welch formation, particularly its marked uniformity as represented by many samples, and other characters, taken in conjunction with the evidence of early Mississippian shale at least locally at its base, strengthens assignment of the Welch chert to the Mississippian. If this is really a correct assignment, it follows that débris derived from the chert, possibly indistinguishable from it lithologically, may belong to the early Pennsylvanian. Further, if correlations are not erroneous, the cherty material in the Sheridan well, Ellsworth County, that overlies shale from which undoubted Pennsylvanian fossils appear to have come, may be regarded as such early Pennsylvanian re-worked chert; or, though the writer does not believe that the Sheridan well fossils may be explained away in some fashion, it is conceivable that this record is in error. Accumulating evidence from drilling, especially that consisting of well samples, will contribute to a definite solution of sub-surface stratigraphic problems in central Kansas, but it is, of course, very desirable to secure additional paleontologic testimony.

RAYMOND C. MOORE

LAWRENCE, KANSAS
October 25, 1927

DISCUSSION

THE EFFECT OF GRAVITATIONAL COMPACTION ON THE STRUCTURE OF SEDIMENTARY ROCKS[1]

The rôle of gravitational compaction in the origin of certain folds in the Mid-Continent region has been discussed by Mr. Hedberg and myself in recent issues of the *Bulletin*.[2] In this discussion I have apparently failed to state clearly and fully some of the most essential points; therefore, I wish to amplify those statements that seem liable to misunderstanding. Many Mid-Continent folds were not caused by compacting, but several years ago I endeavored to give reasons for thinking that the Fairport-Natoma anticline[3] might be one that was formed by this process. In his original paper Mr. Hedberg rejected this hypothesis on the grounds that his method for testing the compaction theory showed it to be quantitatively improbable when applied to this particular anticline. My discussion of his paper was intended primarily to show that his method, though qualitatively correct, was too uncertain to afford a valid disproof of the suggested explanation of this fold. In order to demonstrate this uncertainty I endeavored to show that, by another method (perhaps but one of several possible alternatives), his own data led to conclusions quantitatively very different from those he reached. In his reply, Mr. Hedberg criticized my objections and alternative proposals very thoroughly.

Neither the proposed interpretation of the Fairport-Natoma anticline nor my alternative method for testing compaction theories is well established. The one is based upon merely reconnaissance mapping and the logs of the first few wells in the field, the other upon the few available porosity determinations of shale and clay. Hence, I willingly concede, now as before, that my explanation of the anticline may be wrong and that this alternative method and my suggested depth-porosity equation are not the final answer to the whole question of the compacting of shale. In fact, I said,

> It seems unbelievable that the porosity of clay and shale should vary so regularly with depth, and we would expect that some other relation holds, at least at very shallow depths. However, the available data of any sort are so meager and fit the simple equation so closely that there seems to be no adequate justification for assuming as a first approximation some complex relation between the two variables.

[1] Published by permission of the director, U. S. Geological Survey.

[2] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1035–72; Vol. 11 (1927), pp. 621–32, 875–86.

[3] W. W. Rubey and N. W. Bass, "The Geology of Russell County, Kansas," *State Geol. Surv. Kans. Bull. 10* (1925), pp. 66–85.

A third and more complex relation between depth and porosity that might be worth testing is even more nearly identical with Sorby's theory than either Mr. Hedberg's or mine and, theoretically at least, it should avoid improbabilities at both shallow and great depths. Sorby[1] postulated that a clay particle is deformed like a beam resting upon two supports and that the volume of voids between particles is a measure of the distance between these supports. From these postulates he derived equations that reduce to the assumption that load or depth varies inversely with the ratio, $\frac{\text{present porosity}}{\text{initial porosity } \textit{minus} \text{ present porosity}}$.
If this relation is correct and if the porosities of clay at different depths or pressures are known, the initial porosities at zero depth or pressure (that is, at the mud-water contact) can be computed without any additional assumptions. This third possible relation between overburden and porosity seems to fit Mr. Hedberg's laboratory and well data fairly closely. Furthermore, it does not require, like one of the equations I proposed, different exponents to take account of different lithologic types because each type has a different initial porosity. However, it demands laborious mathematical treatment to apply it to compaction theories. And unfortunately, it fits Mr. Hedberg's well data best if the initial porosity had once been nearly 100 per cent. Some experimental evidence[2] suggests that clays flocculated in salt water, such as the well samples, may have initial porosities much nearer 100 per cent than those deposited in fresh water, such as the laboratory clays. Nevertheless, this effect of salinity on porosity is not sufficiently well established to serve as a basis for a theory of compacting. Therefore, the fact that the laboratory and well data seem to fit this one fundamental relation indicates that compacting is due to one physical process at all depths; but on the other hand, the fact that the well samples indicate high initial porosities simply leads us back to the previous depth-porosity equation that Mr. Hedberg criticizes.

Yet an assumption much more fundamental than the precise form of the depth-porosity relation underlies and greatly affects the reliability of any method of testing compaction theories. Both Mr. Hedberg's and my alternative method rest on the assumption that the increase, with depth, of the closure over a buried hill was caused by the continual deposition of more shale in the sags on the sea floor surrounding the site of the buried hill than upon the low mound that lay above each buried hill. Otherwise, as he said, "the closure in a bed at any distance above the base would be the same as in the basal key bed." That is to say, we both assume strictly similar folding. Although this assumption may be correct, I had hoped to point out by analogy with a bed-roll that the greater deformation at depth might possibly be due in part to distortion by compacting

[1] Henry Clifton Sorby, "On the Application of Quantitative Methods to the Study of the Structure and History of Rocks," *Quart. Jour. Geol. Soc. London*, Vol. 64 (1908) p. 230.

[2] Carl Barus, "Subsidence of Fine Solid Particles in Liquids," *U. S. Geol. Survey Bull. 36* (1886), pp. 31, 35.

over an irregular floor instead of to the continued deposition of more mud around, than upon, buried hills. Mr. Hedberg himself says, in another connection, that "perfectly similar folding must be rare indeed." The bed-roll mattress smooths out irregularities even though the same thickness of bedding is deposited over the entire area, and any analogous stretching and squeezing of strata during settling over buried hills would cause sharper folds with depth. The amount of closure on deeper sharper folds formed in this manner could not be calculated even approximately by the particular methods that either of us used.

Mr. Hedberg thinks that, regardless of the form of the depth-porosity relation or of the method of compacting, the Fairport-Natoma anticline could not have been formed by this process because of the unconformity between Cretaceous and Permian rocks. But does this really disprove compacting? The amount of erosion in Russell County represented by this unconformity is unknown. Moreover his porosity determinations of Cretaceous and Paleozoic shales from the Ranson well seem to fall into a single smooth curve, and it therefore appears that elsewhere in western Kansas this same erosion interval did not perceptibly alter the depth-porosity relation. Furthermore, many anticlines and domes in the Mid-Continent and Rocky Mountain fields are topographic "highs" today; consequently, there seems little reason to think that all topographic expression of folds would have been removed by the pre-Cretaceous erosion.

I am very sorry if I misinterpreted Mr. Hedberg's estimate of the accuracy of his method of testing the theory of compacting. His method indicated (p. 1070) that the supposed hill underlying the Fairport-Natoma anticline was more than 1,000 feet high, but by other means of approach, I estimated its height at something like 400 or 600 feet. And, in discussing the Woodson County fold, on page 1068, he concluded that, because of the exceptional conditions dependent on the presence of the Cherokee shale there, the figures of the first three columns of his table might be subject to increases of 50, 30, and 20 per cent. These applications and statements led me to think that Mr. Hedberg considered his method accurate to within half the computed values; otherwise it seemed he would not have used it as a test.

One of my objections to his method was that his detailed data, even when the most favorable estimates for the eroded thickness are made, fall far off the general depth-porosity curve on which his method is based. Making what seem to be reasonable estimates of the thickness of eroded rocks, one finds that the two most carefully studied wells show shale porosities of about 25 and 10 per cent at a depth where his average curve shows 20 per cent porosity. The Lynn well, in order to fit his curve, requires an eroded overburden of at least 4,000 feet. In his reply, Mr. Hedberg seems to favor some such figure, although stratigraphic evidence makes this seem several times too great. Even granting whatever overburdens are most favorable to his case, the individual curves still show very different slopes from his average curve and cross it at perceptible angles.

Objection must also be made to Mr. Hedberg's conclusion that his average curve can only be applied to an area by correcting for the amount of shale in the buried rocks. His average curve was based largely on the Ranson well and, according to the drillers' log, the Ranson well itself penetrated something like 30 to 60 per cent of shale. It was this series of various rock types—not a section of pure shale—that was used in preparing his general curve. Hence, unless the amount of shale underlying an area is unquestionably different in its proportion or character from that in the Ranson well, an additional allowance for the amount of shale underlying an area is unjustified.

The proportion of shale underlying any given area is but one of many factors that would influence the depth-porosity relation. Any conditions that would change the composition of a compacted rock or affect the initial porosity, the compactibility, or the weight of overburden, would also be important. As the depth-porosity curves of different wells do not fall into any one average curve, it appeared to me better to use what seems to be the general mathematical *form* of all the curves and to determine from local observations in each area the local differences in the *slope* (the different constants in a fundamental equation). Mr. Hedberg objects to changing these constants from one well to another; but to me it seems that this procedure cannot be avoided. I interpret the constant in the proposed depth-porosity equation as a measure of the important geographic variations. For example, in one area the stratigraphic section may consist almost entirely of rather uniform, readily compactible shale; elsewhere the shale may be interlaminated with a large proportion of some other much less compactible rocks. Or in one place the average density of the rocks may be 2.0, and in another 2.7. These and other factors that vary geographically, such as the number and importance of obscure unconformities within a section, the location with respect to margins of depositional basins, and the amount of lateral compression a region has undergone would profoundly affect the value of the constant in the proposed depth-porosity relation.

Mr. Hedberg and I concur on the importance of lithologic variation in compacting. Both his and Terzaghi's laboratory data show clearly that the percentage of clay in a sediment is a most important factor in its compactibility. I am now comparing the clay content, the probable depths of burial, and the porosities of outcrop samples that I collected in northeastern Wyoming to represent a stratigraphic section of about 4,000 feet of Cretaceous shales. I wish to join Mr. Straub[1] in recommending that members of the Association determine the porosity of shale samples from deep wells wherever practicable, and this study of Wyoming shales leads me to add that, for these determinations to be most useful, the samples should also be mechanically analyzed.

William W. Rubey

Washington, D.C.
October 18, 1927

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 889–91.

REVIEWS AND NEW PUBLICATIONS

Oil-shales of the Lothians (3d ed). *Memoirs of the Geological Survey of Scotland.* H. M. Stationery Office, Edinburgh, 1927. 264 pp. Price 5*s.* 6*d.*

The first edition of this most valuable work was published in 1906, and the second in 1912. The present volume has been revised and brought up to date and contains many new data regarding the geology of the Scottish oil-shale fields and the commerical development of the oil shales through an industry which has since 1888 been mining and treating between two and three million tons of oil shale annually and at the present time employs about fifty thousand people.

The volume is divided into four parts, each written by a man whose authority on the subject treated is unquestioned. Part I, "The Geology of the Oil-Shale Fields of Scotland," is by R. G. Carruthers, and is accompanied by an excellent geologic map in color. The discussion includes the following topics: geological position and distribution of the oil shales, physical characters, geological zones, geological structure, detailed description of the shale fields and deep borings. Part II, "Methods of Mining the Oil Shales," by W. Caldwell (pp. 115–57), goes into the subject of the search for shale, mine development, timbering and ventilation, water disposal, and ore transportation. The chapter is profusely illustrated. Part III, "The Chemistry and Technology of the Oil Shales," by E. M. Bailey, is treated under the following heads: (1) raw materials (pp. 158–72), oil shale, characteristics and occurrence, kerogen, its nature and origin, and the chemical composition of oil shale with laboratory yields of oil and ammonia, (2) chemical composition of shale oil (pp. 172–75), (3) yield of crude oil and ammonia (pp. 175–90), variations, effect of heat, yields and quality of crude oil from different types of retorts, (4) process of manufacture (pp. 190–217), production of crude oil and sulphate of ammonia, refining of crude oil, (5) products and cost of manufacture (pp. 217–25), (6) occurrence of natural oil in the shale fields (pp. 226–30), (7) occurrence of natural gas in the shale fields (pp. 230–36), and (8) statistical tables (pp. 236–39). Part IV, "History of the Scottish Oil-Shale Industry," by H. R. J. Conacher (pp. 240–65), gives a complete connected story of the development of this great industry from its beginning in 1851 down to the present.

This volume is packed with facts about the great oil-shale industry of Scotland and those who are in any way interested in the possible development of a similar or greater industry in the United States may well use the information contained in the book as a foundation upon which to build. All geologists interested in petroleum should acquaint themselves with this most interesting subject for scientific reasons if for no other.

DEAN E. WINCHESTER

DENVER, COLORADO
October, 1927

RECENT PUBLICATIONS

IDAHO

"Oil Possibilities of Melon Valley Near Buhl, Idaho." *Press Bulletin No. 16, September, 1927.* Bureau of Mines and Geology, University of Idaho, Moscow, Idaho.

THE ASSOCIATION LIBRARY

Headquarters acknowledges library accessions:

GENERAL

From J. Harlan Johnson:

"Bibliography of Geophysical Principles, Apparatus and Methods Applied to Prospecting"

"Continental Drifts, or the Displacement Theory"

From Swedish American Prospecting Corporation:

"Electrical and Electromagnetic Prospecting," by Hans Lundberg

"Electrical Prospecting at the Britannia Mine," by James I. Moore and Frank Erbutt

"Methods of Electrical Prospecting," by Hans Lundberg

"Modern Geophysical Methods Used in Prospecting," by Hans Lundberg and Allen Rogers

From J. Versluijs:

"An Hypothesis Explaining Some Characteristics of Clay"

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"Bibliography of the Geology of Southeastern Colorado," 1925

"Bibliography of the Geology of Southwestern Colorado," 1924

"The Geology of the Golden Area, Colorado," Quarterly of the Colorado School of Mines, July, 1925

"Mining Districts in Colorado," by J. Harlan Johnson and W. A. Waldschmidt, 1924

From F. C. Proctor:

"The Oil Problem"

SWEDEN

From Swedish American Prospecting Corporation:

"Electrical Prospecting in Sweden," by K. Sundberg, H. Lundberg, and J. Eklund

TECHNICAL PERIODICALS

In addition to the list published in the November *Bulletin* the following exchange periodicals are received at headquarters:

Geologische Rundschau (Berlin)
Oil Field Engineering (Los Angeles)
Senckenbergiana (Frankfurt a. M.)
Transactions of the Thermo-Technical Institute (Moscow)

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THE ASSOCIATION ROUND TABLE

REVOLVING PUBLICATION FUND

After paying the immediate expenses of the meeting itself, the local committee on arrangements for the New York fall meeting of 1926 had a residue of about $4,000 which it might have spent in printing the special papers on the program, thus satisfactorily using the funds contributed for the success of the meeting. The New York committee has done not only this, but more; it has provided for the special publication of the Continental Drift symposium papers presented at New York, and has proposed that all income derived from the publication of these papers become the nucleus of a fund for the special purpose of printing books and papers in addition to the regular *Bulletin* publication. This farsighted plan has been approved and the money accepted by the executive committee in behalf of the Association. The executive committee is to administer the fund. Thus is established the Association's Revolving Publication Fund. With care, this should be not only a continuing fund, but a gradually increasing fund. It has become more and more evident that many valuable geological manuscripts would be more readily available to the Association were it not for the *Bulletin's* somewhat limited resources for publication. Special publications outside of and in addition to the *Bulletin* will meet a need and prove to be popular. The special volume on *Salt Dome Oil Fields* has been a distinct success.

The Association is indebted to the New York local committee and contributors. It is hoped that the fund will be augmented by sums similarly available elsewhere.

THEORY OF CONTINENTAL DRIFT

The first book published by the new Revolving Publication Fund is to be the special symposium held in conjunction with the New York meeting of November, 1926, on *The Theory of Continental Drift.* Those who attended this discussion of Wegener's hypothesis of the origin of continents and oceans, held in the auditorium of the Engineering Societies Building in New York City, remember the several speakers of wide reputation. The contributors to this book are international authorities: W. A. J. M. van der Gracht (Marland Oil Company), Bailey Willis (Stanford), Rollin T. Chamberlin (Chicago), John Joly (Trinity, Dublin), G. A. F. Molengraaff (Delft), J. W. Gregory (Glasgow), Alfred Wegener (Graz), Charles Schuchert (Yale), Chester R. Longwell (Yale), Frank Bursley Taylor (Fort Wayne, Indiana), William Bowie (U. S. C. and G. Survey), David White (U. S. G. S.), Joseph T. Singewald, Jr. (Johns Hopkins), and Edward W. Berry (Johns Hopkins).

With this array of authors representing world-wide scholastic thought and

equally reputable government and industrial research, this book should find a ready place in university and public libraries as well as on the desks of all real students of the earth. Dealing with the larger aspects of continental formation and configuration, these several writers do, nevertheless, contribute much to the solution of more limited and local problems of structural geology. Such different —and related—earth sciences as geophysics, paleobotany, climatology, and petrology play their part in answering our questions about the present condition of the earth.

In accordance with the Association plan for uniform style of publication, the new book will be of standard size and cloth binding like the salt dome volume. It will contain approximately 250 pages with an index and illustrated with black-line drawings and halftones. The book is now in press. The published price is $3.50, postpaid. Orders received from Association members before January 1 will be filled at $3.00 a copy. None of the Continental Drift papers will appear in the *Bulletin*. Order from headquarters, Box 1852, Tulsa, Oklahoma.

CALIFORNIA IN MARCH, 1928

Keep in mind the dates of the thirteenth annual convention. The meeting is to be held in San Francisco, March 21, 22, and 23, and special features are being planned in Los Angeles, March 24 and 25. Special railroad rates are being arranged. Begin to make your plans now.

PAY ANNUAL DUES JANUARY 1

The regular annual dues of an active member are $15.00, of an associate member $10.00. *The 1928 dues are payable January 1.* Failure to pay promptly handicaps the Association's activities and service to members. Any member failing to meet this obligation will not receive the *Bulletin*. Any member in arrears for a period of one year may be dropped from membership.

GENERAL BUSINESS COMMITTEE

The Executive Committee met at Ponca City, Oklahoma, October 18. Members present were G. C. Gester, president, Luther H. White, vice-president, David Donoghue, secretary-treasurer, and John L. Rich, editor. Elections of district representatives on the new general business committee of the Association were accepted and approved as shown on page 1343.

The business manager was instructed to notify the new district representatives of their election by the local groups and approval by the Executive Committee. The terms of the new representatives commence with the meeting of the general business committee of the thirteenth annual convention at San Francisco in March, 1928, and continue until the meetings of the business committees in the years shown after their names. The regional directors, now holding office

DISTRICTS AND REPRESENTATIVES

DISTRICT	REPRESENTATIVE Term ending spring of year shown	ADDRESS
Amarillo	C. Max Bauer (1931)	Midwest Refining Company, Box 972, Amarillo, Texas
Appalachian	K. C. Heald (1929)	1161 Frick Building Annex, Pittsburgh, Pennsylvania
Ardmore-Oklahoma City	S. H. Woods (1930)	Box 296, Ardmore, Oklahoma
Canada	O. B. Hopkins (1930)	Imperial Oil Company, 56 Church Street, Toronto, Canada
Capital	H. D. Miser (1931)	U. S. Geological Survey, Washington, D.C.
Dallas	Willis Storm (1931)	710 Republic Bank Building, Dallas, Texas
Enid	Glenn C. Clark (1931)	Marland Refining Company, Ponca City, Oklahoma
Fort Worth	H. B. Fuqua (1930)	Box 737, Fort Worth, Texas
Great Lakes	A. C. Trowbridge (1929)	1182 East Court Street, Iowa City, Iowa
Houston	J. M. Vetter (1929)	Rio Bravo Oil Company, Houston, Texas
Mexico	S. A. Grogan (1929)	Apartado 106, Tampico, Mexico
New York	W. B. Heroy (1929)	19 Wayne Avenue, White Plains, New York
Pacific Coast	C. R. McCollom (1931)	Union Oil Company, Union Oil Building, Los Angeles, California
	N. L. Taliaferro (1930)	Bacon Hall, University of California, Berkeley, California
	C. M. Wagner (1929)	1003 Higgins Building, Los Angeles, California
Rocky Mountain	Alex W. McCoy (1931)	Drawer 1169, Denver, Colorado
	Charles M. Rath (1929)	Box 240, Denver, Colorado
San Angelo	Edgar Kraus (1929)	Box 817, San Angelo, Texas
Shreveport	W. E. Hopper (1930)	Southwestern G and E Company, Box 1106, Shreveport, Louisiana

DISTRICTS AND REPRESENTATIVES—*Continued*

DISTRICT	REPRESENTATIVE Term ending spring of year shown	ADDRESS
South America	(1930)	
Tulsa	Sidney Powers (1931) Robert J. Riggs (1930) A. F. Truex (1929)	Box 2022, Amerada Corporation, Tulsa, Oklahoma Drawer L, Bartlesville, Oklahoma 1815 Easton Place, Tulsa, Oklahoma
Wichita	Marvin Lee (1930)	612–16 Brown Building, Wichita, Kansas
Wichita Falls	C. W. Clark (1931)	717 City National Bank Building, Wichita Falls, Texas

by appointment of the president, have consented to serve until the new business committee meets next March.

Any member of the Association wishing to bring new business before the Association should present it to his district representative who will lay it before the business committee at the annual meeting.

President Gester has appointed C. R. McCollom, of Los Angeles, chairman of the general business committee.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

FOR ACTIVE MEMBERSHIP

Charles F. Bassett, Maracaibo, Venezuela, S.A.
J. B. Burnett, E. L. Estabrook, C. H. Wegemann

Carlyle D. Johnson, Denver, Colo.
A. E. Bainerd, M. G. Gulley, Irvine E. Stewart

Albert C. Price, Maracaibo, Venezuela, S.A.
Frank Bryan, H. M. Scott, Robert E. Garrett

Jean C. Thompson, Tulsa, Okla.
Robert E. Garrett, Carl W. Clarke, Robert H. Wood

Herbert C. G. Vincent, Los Angeles, Calif.
E. F. Davis, Frank S. Hudson, Roy R. Morse

FOR ASSOCIATE MEMBERSHIP

Richard E. Koch, Basel, Switzerland
H. E. van Aubel, Theron Wasson, Sidney Powers
Lynn K. Lee, Tulsa, Okla.
A. A. Langworthy, V. E. Monnett, Charles E. Decker
Howard Warren, Bartlesville, Okla.
W. L. Walker, C. J. Peterson, G. H. Westby
Edward R. Woolfolk, Bartlesville, Okla.
E. E. Lindeblad, W. L. Walker, C. J. Peterson

FOR TRANSFER TO ACTIVE MEMBERSHIP

Virgil B. Cole, Shawnee, Okla.
W. B. Wilson, W. R. Longmire, A. I. Levorsen
Arthur M. Meyer. Ardmore, Okla.
John R. Bunn, George E. Burton, Charles E. Clowe
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Memorials

STUART WELLER

The November number of the *Bulletin* carried a brief notice of the death of Dr. Stuart Weller, professor of paleontologic geology and director of the Walker Museum of the University of Chicago.

Dr. Weller had spent part of the summer with a large group of advanced students at the field camp of the university in the foothills of the Ozarks, the gift of W. E. Wrather, going from there to Kentucky to continue work he was doing, as the assistant geologist, on the geology of the Smithland quadrangle. A severe attack of what seemed acute indigestion, but which proved to be angina pectoris, led him to make plans for an immediate return to his home, and he was being taken to the railway station when the end came. The first intimation given his family of his illness was the message telling of his death.

In Dr. Weller's untimely death the cause of science has suffered an irreparable loss, but the work to which he gave "the last full measure of devotion," will be carried forward by the students who have had the advantage of his thorough training in the classroom, laboratory, and that larger laboratory, the field, in which he ever took such keen delight, and who have been stimulated by his example and have caught something of his spirit. To those students he was more than a teacher. He was a friend; always approachable, always helpful, always inspiring, by precept and example, to higher endeavor.

To the University of Chicago he gave thirty-two years of distinguished service, and it is indebted to him not only as an educator, but for the invaluable collections secured through his efforts—collections such as those of Hall, Gurley, and Sir John Van Horn. Recently it has been made possible for some of this valuable material, which has been boxed for years, to be displayed in appropriate setting, and available for use. Dr. Weller had plans for the development of Walker Museum which extended far into the future, and he has a lasting memorial in his splendid contributions to the treasures of the Museum.

His association with the U. S. Geological Survey, and with those of Illinois, Missouri, Kentucky, and New Jersey, covered a period of many years, but the work with which his name will most closely be linked will probably be that done on the Mississippian formations under the Illinois Geological Survey, with which he had been identified from the start. Dr. T. E. Savage, of the University of Illinois, says of this work: "Our present knowledge of the Mississippian rocks and their fossils is largely the result of his untiring and painstaking work. To this problem Professor Weller applied his keen and brilliant mind through many years." In later years his work centered on the Chester formations in the upper portions of the Mississippian, and he mapped these formations in their extent from St. Louis southward and eastward into Kentucky.

F. W. DeWolf, a former director of the Illinois Survey, says of Dr. Weller's work: "He was a tireless worker, always open-minded, and impressing on his student assistants the importance of sane methods of interpretation, and while there was at times some controversy with earlier workers on the area, his attitude was always that of a scientist and a gentleman." Mr. DeWolf also calls attention to his admirable systematic office work in these words: "At the end of the field season his collections were promptly prepared for study. His notes were made carefully in standard form and were filed in loose-leaf binders, thus facilitating their final preparation. A full feeling of responsibility to the science and to his employers made him a prompt and efficient producer of the results of his investigations, and has influenced a large number of fellow scientists to search for the truth and place it promptly at the service of fellow-workers." Without doubt this systematic habit will greatly facilitate the completion of unfinished material, much of which was almost ready to be released for publication.

Much that was of interest concerning the early student life of Dr. Weller was learned from Dr. E. M. Shepard, his professor and friend at Drury College, Springfield, Missouri. His father came to this country from England, entered the ministry of the Congregational church, and moved his family to Springfield to give his children the advantages offered by Drury College. It was his ambition that Stuart should enter the ministry, but very early he showed a marked scientific bent, with a decided leaning toward botany, and a flora collected during these preparatory days later became a part of the permanent collection of Cornell University.

He became interested in geology through the collection of fossils made under the direction of his instructor, Dr. Shepard, and when only sixteen he had made a remarkable collection. The knowledge that similar fossils were considered of sufficient importance to warrant their description and illustration in a scientific bulletin strengthened his interest in geology, and this interest was crystallized by contact with Dr. H. S. Williams, who, recognizing the boy's promise, persuaded him to go to Cornell University. While there he worked as a laboratory assistant, and received the A.B. degree in three years, then going to Yale, where he secured a fellowship, and where the degree of Ph.D. was conferred on him in 1901. He was married to Miss Harriet Marvin, a fellow student at Drury College, and she, with three sons, survives him. One of his sons has chosen his father's profession, and the years of close association, and familiarity with his father's methods, may mean that he will take up the task which Dr. Weller had to lay down all too soon.

C. E. Decker

EWART GLADSTONE SINCLAIR

The press reports of June 25 brought the sad news of the sudden death of E. G. Sinclair. He was killed by the accidental discharge of a rifle while on a hunting trip near his ranch in Montana.

E. G. Sinclair was born in 1884 on a ranch in North Dakota, his parents being Mr. and Mrs. J. B. Sinclair. To his boyhood training on the frontier

farms of Dakota he doubtless owed much of his great physical strength, and his ability to meet and overcome the hardships of Nature, rugged mountains, dry deserts, the cold of Alaska, and the heat of the South American tropics.

He was of the sturdy, self-reliant type and did not ask odds from either man or Nature in his effort to gain an education or later in carrying out his work as an engineer and a geologist. Some of his friends perhaps only saw this side of his life, but there are many to whom he came in time of sorrow or worry and they learned that he had a heart full of tender sympathy and a broad view of life that made it possible for him to be a most helpful advising friend in time of trouble.

He had a thorough training as a surveyer before taking up his university studies in mining, engineering, and geology. While earning money to carry himself through college he was topographic surveyor on an extensive reclamation project on the Rimpau River in Peru in 1905. His six months of work there helped to turn a region of fever-breeding swamps into healthful sugar plantations, but for him the reward was a hard fight with malaria and two years spent in mining in Alaska to free himself of the fever poisons of the tropics.

He made two other trips to South America, once under the direction of Ralph Arnold for the Barber Asphalt Company to the Maracaibo Lake region in 1913. In July, 1926, he went again to Venezuela, this time as a geologist for the Beacon Sun Oil Company.

After graduating from Stanford University in geology and mining in 1911 he was a division geologist with the California Highway Commission in 1912 and a resident engineer in charge of highway construction for the same Commission in 1913. He was a miner in Alaska in 1905 and 1906 and was assistant foreman of the Tramway mine in Butte, Montana, from 1916 to 1919.

In 1919 the Oregon Bureau of Mines employed him as assistant chief geologist to make a survey of western Oregon for the possibilities of oil and gas, and he gave most valuable service in the field work and preparation of the bulletin published by the Bureau.

In December, 1919, he joined the geological force of the Midwest Refining Company and in May, 1921, was put in charge of the Wyoming division for this company. In March, 1923, he was made district superintendent in the producing department for Wyoming and Montana. In July, 1926, he terminated his work with the Midwest Refining Company to go to South America for the Beacon Sun Oil Company.

E. G. Sinclair was a trained surveyor and engineer before he took up his work in geology and his great successs as a structural geologist was due to his use of engineering principles in the solving of geological problems. His years of experience as a mining engineer in underground work, especially in the study of faults, was invaluable to him in his work as a petroleum geologist.

He is survived by Mrs. Sinclair, who before her marriage was Marcia Drucker Lever of Redlands, California, alumna of Stanford University, his four sons and two daughters, his parents, one sister, and two brothers.

CLARENCE B. OSBORNE

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WALTER B. JONES, formerly assistant state geologist under EUGENE A. SMITH, was appointed state geologist of Alabama commencing with October.

The American Petroleum Institute Gas Conservation Committee has appointed the following regional directors for the study of the value of natural gas in the conservation and production of petroleum: W. P. HASEMAN, of the Marland Oil Company, Ponca City, Oklahoma, for Oklahoma and Kansas; M. E. LOMBARDI, of the Standard Oil Company of California, for California; MAX W. BALL, of Denver, for the Rocky Mountain area; and JOHN R. SUMAN, of the Humble Oil & Refining Company, Houston, for the Texas and Louisiana area. EARL OLIVER, petroleum engineer of Ponca City, is general secretary for the study.

DOUGLAS R. SEMMES, consulting geologist of Cisco, Texas, spent the summer in Canada, the western United States, and Mexico.

ROBIN WILLIS, of the Marland Oil Company of Texas at Fort Worth, and Miss ALICE BURKE, of the Marland Oil Company of Delaware at Ponca City, Oklahoma, were recently married.

FREDERICK P. VICKERY and R. H. GARRISON have an article on "The Goleta Field," of California, in the October number of *Mining and Metallurgy*.

H. J. WASSON is the author of an article on "Recent Oil Developments in Venezuela" in the October *Mining and Metallurgy*.

R. J. ST. GERMAIN, of Tulsa, spent two months in Canada last summer.

The Association of Petroleum Conservation Bureaus was organized at Tulsa, Oklahoma, at the time of the Fourth International Petroleum Exposition last October. The officers are: president, W. F. CHISHOLM, director of the minerals division of the Louisiana department of conservation; vice-president, HALE B. SOYSTER, director of the conservation branch of the U. S. Geological Survey at Muskogee, Oklahoma; and secretary, MANUEL J. ZENADA, director of the petroleum department of Mexico, bureau of industry, commerce, and labor.

HERALD BROTHERS have dissolved their partnership as consulting geologists. JOHN M. HERALD retains the office and consulting practice and FRANK A. HERALD is now president of the Phoenix Oil and Transport Company. The address of each remains the same, 303 Cosden Building, Tulsa, Oklahoma.

JUSTUS H. CLINE, of Wichita, Kansas, spent two months in Alaska last summer.

VALENTINE R. GARFIAS, of H. L. Doherty & Company, 60 Wall Street, New York City, had an article in the *Oil Weekly* of October 7, giving a preliminary estimate of the world's petroleum production for 1927.

JOHN SMITH IVY and Miss CARO GAYLE were married October 7, 1927, at the home of the bride's parents in Shreveport, Louisiana. Mr. Ivy is chief geologist for the Palmer Corporation at Shreveport.

The Shreveport Geological Society held its first fall meeting October 7 and elected the following officers for the new year: president, GEORGE R. STEVENS, of the Simms Oil Company, Ricou-Brewster Building; vice-president, C. C. CLARK, of the Roxana Petroleum Corporation, Giddens-Lane Building; and secretary-treasurer, C. D. FLETCHER, of the Gulf Production Company.

GEORGE L. ELLIS, who was at Moab, Utah, during the past summer, is now situated at 839 Kennedy Building, Tulsa, Oklahoma.

LEWIS B. KELLUM, of Tampico. Mexico, moved temporarily to Eagle Pass, Texas, last October.

RALPH W. RICHARDS, recently of Washington, D.C., moved to Maracaibo, Venezuela, in October.

CARY P. BUTCHER, west Texas district geologist for the Kirby Petroleum Company for the past two years, is now district geologist for the Continental Oil Company at San Angelo.

H. T. BECKWITH has not joined the geological force of the Transcontinental Oil Company as was erroneously stated in the September *Bulletin*.

W. L. FOSTER, head of the department of geology at the University of Tulsa, provides an extension course for business men two nights of each week. At the end of the term, a field trip is made to the Arbuckle Mountains.

H. J. STEINY is in charge of the Los Angeles geological office of the Associated Oil Company, with supervision over the company's resident geologists in California and Colorado.

The petroleum division of the American Institute of Mining and Metallurgical Engineers has planned a trip to the West Indies and a visit to the Venezuela oil fields. The steamer "Lapland" is expected to sail from New York January 25 and return February 19.

H. D. EASTON published a paper in the *Oil and Gas Journal* of October 13, on the Monroe gas field and northern Louisiana structure.

Mr. and Mrs. THOMAS C. HIESTAND announce the arrival September 9 of twin boys belonging to the six-pound variety. These boys are facing a hard and rocky future, as Mrs. Hiestand is also an experienced geologist. Mr. Hiestand is stationed in Tulsa with W. C. McBride, Inc.

R. R. THOMPSON has severed connections with R. S. King and has opened an office in association with Corzelius Brothers and Taggart, drilling contractors, at 703 W. T. Waggoner Building, Fort Worth, Texas.

Frank Gouin is engaged in consulting work at Duncan, Oklahoma.

F. B. Plummer returned to Fort Worth in October after a visit to New Hampshire.

Rae Preece, of San Antonio, Texas, has resigned from the Douglas Oil Company, and is engaged as an independent operator.

D. M. Cottingwood is in charge of geophysical work for the Sun Oil Company.

The executive committee of the Association met in Ponca City, Oklahoma, October 18. President Gester reported progress on plans for the thirteenth annual convention at San Francisco, March 21–23, and at Los Angeles, March 24–25, 1928.

R. C. Brehm is presenting the subject of micro-paleontology to advanced students at the Colorado School of Mines.

Howard Clark completed his work with the Mississippi River Commission last October and is again on the geological staff of the National Refining Company at Abilene, Texas.

Conrad K. Bontz, geologist with the Standard Oil Company, died in Brazil, September 22.

M. J. Hopkins has written on "Geologists All" in the *Engineering and Mining Journal* for October.

W. S. Levings is an instructor in geology at the Colorado School of Mines at Golden.

F. H. Lahee, chief geologist of the Sun Oil Company, returned to Dallas, October 8, from a two months' business and vacation trip in Europe.

Fred M. Bullard, associate professor of geology and mineralogy at the University of Texas, Austin, Texas, is on leave of absence for a year at the University of Michigan completing work for a doctorate. Mr. Bullard spent the past field season connected with the Oklahoma Geological Survey under which supervision he studied the Cretaceous of western Oklahoma and adjacent areas.

Frederick G. Clapp, consulting geologist of 50 Church Street, New York City, is in Persia as consulting petroleum engineer for the Imperial Government of Persia.

O. L. Brace, geologist with the Marland Oil Company of Texas, formerly stationed at Shreveport, Louisiana, is spending the winter at Laredo, Texas, working on some special company reports.

P. C. Murphy is general manager of Humphreys Brothers, Inc., and Humphreys Corporation. His office is in the Esperson Building, Houston, Texas.

Leon E. English had an article on "The Geology and Development of Hiawatha Anticline, Sweetwater County, Wyoming, and Moffatt County, Colorado," in the *Inland Oil Index* for October 28.

GEORGE OTIS SMITH, director of the U. S. Geological Survey, has been nominated for the presidency of the A. I. M. E. for 1928.

R. W. BRAUCHLI, of Anderson-Prichard Oil Corporation, Oklahoma City, spent the summer in Switzerland.

ROBERT BARLING and ROBERT MULDROW have organized the Southwest Elevation Company of Texas at Midland. They are prepared to render well elevation service in that area.

JOHN WELLINGTON FINCH is lecturing on mining geology and the geology of foreign oil fields at the Colorado School of Mines.

The American Association for the Advancement of Science Section, E (geology and geography) will hold its sessions at Nashville, Tennessee, on December 27 and 28, 1927. The first day will be devoted to a symposium on the Mesozoic-Cenozoic stratigraphy of the Gulf states.

The Geological Society of America and the Society of Economic Geologists will hold their annual meetings at Cleveland, Ohio, on December 29–31, 1927.

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